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A review on sensor based E-health monitoring devices

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Abstract: Sensors integrated with health devices are gaining importance worldwide, due to their real-time monitoring of physiological variables, low cost, self-care, and improved the quality of life. Technology developments with modernization in the internet of things and the telecommunication networks have led a major change in the field of medicine and science. The spread of epidemic novel coronavirus (COVID-19), since the beginning of the year 2020 globally has led the way for identifying the suitable digital technologies which can be used to mitigate the epidemic. This review deliberates on different sensors based on visible light-sensing and infrared technology for remote patient monitoring, materials used in sensors, fabrication of E-health monitoring devices, and their applicability for detection of body temperature, respiration rate, heart rate, blood pressure, blood glucose levels, neural system activity, and electrocardiogram readings. Advances in development of non-contact medical devices is vital for the detection, monitoring, and treatment of highly infectious pandemics like MERS-COV, SARS, COVID-19, Delta variant, Omicron variant and others. The application of the light sensing devices was assessed. The present research should focus on the development of E-health devices that can monitor the physiological variables with potent sensing methods. Visible light-sensing is gaining enormous potential in sensor applications and wireless communication areas because of its availability, eco-friendly, economically viable, and signal processing

Keywords: *Sensors, Devices, Tracers, E-health, Monitoring, Infrared, COVID-19, Visible light, Self-monitoring*

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1. Introduction:

The outbreak of coronavirus epidemic disease 2019 (COVID-19), and Middle East respiratory syndrome (MERS) are the two actively present diseases in the community. COVID-19 is the most highly infectious disease caused due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [1,2]. The epidemic spreads by transmission through airborne droplets emitted through sneeze and cough of the infected, direct contact of an infected person with other uninfected persons, and direct contact of the objects containing the virus. COVID-19 common symptoms are fever, cough, sneezing, and breathing issues. The critical infected persons will have issues like pneumonia, throat pain, and acute respiratory distress syndrome [3]. The disease has spread to 90% of the countries on earth with high transmissibility and no effective antiviral therapy or vaccine increased the death rate in most of the countries. Presently, The World Health Organization (WHO), have issued some preventive measures like covering the nose and mouth with the mask, washing the hand with soap, social distancing with the other people, self-monitoring, self-isolation for fourteen days if the person is suspect, they are infected with monitoring. Hence, it is important for proper planning, tracing, monitoring, supervision, detection, and prevention of the infection with the digital technologies and sensors. Some of the countries across the world have used the digital technologies like migration maps, smartphones, online payment applications, integration of immigration data for airline travellers, real-time health insurance database, smart gadgets application to measure the pulse rate and web-based health map platforms for pandemic management by surveillance, containment, testing, tracking of people, quarantine/self-isolation, and use in health care [4-8]. Currently, there is research in progress to develop a vaccine to mitigate this epidemic and develop E-health devices for self-monitoring/remote monitoring of the infected. Modernization and technology developments in the field of sensors, internet of things (IoT), the telecommunication networks, and the sensors integrated with health devices are gaining importance due to their low cost, real-time monitoring, ease of use, screening large number, quick drug discovery, self-care, and vaccine developments [9,10].

The major contribution of this review is on the sensor integrated, non-contact health devices, based on visible light and Near-Infrared (IR) sensing technology [11]. The focus is on non-contact E-health devices for identification and monitoring of epidemic diseases which are highly infectious like COVID-19, SARS, and other variants of coronavirus. The devices can measure the important physiological parameters like body temperature, respiration rate, heart rate (HR), heart rate variability (HRV), blood pressure, and blood glucose levels. Developments in the medical fields have increased the potential of visible light-sensing and IR-sensing technology in sensor applications and wireless communication domains because they are eco-friendly and economically viable.

The review paper initially briefs the classification and features of biomedical sensors. Further, the importance and principle of visible light and infrared sensing technologies for different clinical applications are discussed. This paper also discusses on the non-contact E-health devices, their theory, the principle of operation, and construction for monitoring important physiological parameters like body temperature, respiration rate, heart rate (HR), heart rate variability (HRV), blood pressure, and blood glucose levels using visible light and infrared sensing technologies. In the last section, the applications of these devices are demonstrated using experimental findings from different kinds of literature for measuring the vital parameters.

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2. Biomedical Sensors

Sensors are vital components in all devices due to their capabilities like sensitivity, operating condition, accuracy, and response time. Discoveries and developments in the field of sensor technology, communication networks, and the Internet of Things (IoT) has aided the advancements in an extended range of detection, sensing device fabrication, integration of devices, and improved sensing performance at specific target [12]. Biomedical sensors with their specific functionality, low cost, simple in operations, portability, and selectivity criteria are observed as promising substitutes to the expensive analytical instruments in the health care industries [13-16]. Biomedical sensors are used primarily for detecting the physical conditions like body temperature and blood pressure of the patient in clinical research. Secondly, continuous monitoring of heart rate, respiration rate, blood pressure, and blood glucose levels.

Biomedical sensors are categorized in to four subclasses based on the nature of sensing [17-19]. Figure 1 illustrates the classification of biomedical sensors. Physical sensors sense the variations in the physical parameters like geometric, flexible sensors, graphene, and optical fiber sensors. Chemical sensors are responsible to measure any changes in chemical compositions in food, bodies, and the environment. Electrochemical, physiochemical, gas and photometric sensors are types of chemical sensors used for biomedical applications. Bio-potential electrodes are commonly used sensors in the medical field, it includes body surface electrodes, metal plates, intra-cavity/intra-tissue, and microelectrodes are the types of bio-potential electrodes. Field-Effect Transistors (FET) is the class of electrochemical biosensors widely applied for the detection of biological molecules and pathogens. FET sensors can detect SARS-CoV2 virus at low concentration without sample pre-treatment in clinical samples these studies are reported [10]. The construction of the sensor which was fabricated by coating the antibody specific to the virus to detect using graphene sheets the gate of the transistor. The sensor was used to identify and test the COVID-19 patients using their nasal swab specimens are depicted in the previous publication [10]. Biosensors class is the cutting-edge sensors that can be implanted in the human body for sensing proteins, DNA, glucose, etc. The nine features of biomedical sensors are depicted in Figure 2 namely, high selectivity, fast response time, multiple sensing modes, biocompatible & disposable, economic, long self-life, high sensitivity, used in non-contact portable devices, and feasible. All the nine key attributes depicted in the figure are the important feature for the current pandemic crisis initially the sensitivity & selectivity of the biomedical sensors are important for early detection of the epidemic COVID-19. Hence, all nine key features are important attributes for a biomedical sensor.

2.1. Visible Light Sensing

Development in wireless communication has explored the use of the visible light spectrum (400-700 nm) for communication networks. Visible light Sensing (VLS) has tremendous potential to improve the efficiency of sensors and communications because of its low cost, safe, eco-friendly, signal processing, and prevalent features. Exponential growth in data communication has led to the implementation of the Internet of Things (IoT) for connecting people, processes, things, and data. Hence, a breakthrough in VLS technologies has been created in wireless communication [20]. The visible light communication system consists of a visible light source, mainly the Light Emitting Diode (LED) emits the light signal towards the infected/uninfected person. The amplitude of the light signals transmitted is modulated periodically due to the physiological movements of the infected/uninfected and reflected by the receiver. These receivers are photo sensors

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that capture the visible light signals and process algorithms to convert them to display signals [21, 22].

2.2 Infrared Light Sensing

Near-Infrared light (NIR) sensing technology is extensively used in biomedical applications, mainly in situ measurements. The spectrum of NIR wavelength range between 650 to 850 nm can penetrate the body tissues and allow physiological parameter measurements through tissue, muscle, fat, and body fluids. Hence, it is one of the favourable electromagnetic spectra for biomedical applications. The NIR sensing and visible sensing are the same with a different light source, amplifiers, and algorithms to process the signals. Developments in the fiber optics domain have increased the potential of NIR spectra in biomedical sensors for clinics and labs [22;23-26].

3. Non-Contact E-Health Devices

International researchers are researching the non-contact monitoring of the vital signs of life. These vital signs are very critical or assessing the health of infected or uninfected patients. It gives timely statistics of the patient about his/her physiological state, which is a very important parameter for a COVID-19 patient. The measurement of physiological parameters like heart rate, heart rate variability, respiration rate, blood pressure, and blood glucose levels are vital signs that can echo the health condition of the patient to some extent during a pandemic. Studies on the epidemic COVID-19 show majorly the respiratory symptoms such as shortness of breath, fatigue, fever, and dry cough [27,28]. All traditional techniques are intrusive and require body contact, bulky, expensive, and time-consuming. Contact during the measurement is not desired in the case of the COVID-19 patients because it can provide a vector for infection. Non-contact vital information is the need of the time during this pandemic. These non-contact devices would not include electrodes and no skin contact. It provides a high sterilized process, hygiene, convenience, and ease of operation.

3.1 Devices for Heart Rate Measurement

Heart rate measurement is discussed carried out using VLS technology, Doppler Effect, Photoplethysmography (PPG) sensors, a combination of PPG sensors in smartphones as smart wearable devices. These sensing elements are combined with digital processor, digital converters, and display systems in a circuit to fabricate the non-conduct health monitoring devices.

3.1.1VLS-Based System for Heart Rate Measurement

Visible light sensing (VLS) based technology can measure the vital parameters, which is a non-contact sensing technology that gives information about breathing and heart rates. The system components include a light source as a transmitter, a photodetector as a receiver, a digital signal processor (DSP) with analog to digital conversion (ADC) unit, and a display screen. The principle of this technology is that a visible light signal is transmitted towards the patient, due to the body movements the amplitude of the signal will be modulated and reflected, based on the skin adsorption capacity of the light. A photodetector captures the reflected signal and processes the same in the DSP unit. Further, the processed signal is displayed on the display screen using basic DSP algorithms [21,29]. Detailed illustration of the mode of measurement carried out will be illustrated in the application of VLS based devices.

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3.1.2 Doppler Effect Based method for Heart Rate Measurement

Heart rate can be measured using sensors like microwave radar and US radar based on the principle of the Doppler Effect. Normally during pumping blood through the cardiovascular system volumetric changes occurs in the heart for each cardiac cycle, these changes result in movement/displacement of the chest due to breathing or due to heartbeat. The chest displacement is measured using microwave radar or US radar-based sensors with adequate resolution [30-32]. Radar microwave sensor was the first instance technology used to measure the variability in heartbeat and respiration rate based on the Doppler Effect. The sensor components are namely transmitter, receiver, frequency oscillator, preamplifier, and data acquisition system [33].

3.1.3 Photoplethysmography (PPG) Based Devices

Photoplethysmography (PPG) device mainly consists of an optical emitter, the light source, and the optical detector. The principal operation of PPG sensors is like visible light and infrared light sensing as shown in Figure 3. The reflected light from the tissue or skin of the infected is proportional to blood volume variations. These variations in the blood volumes and its wave patterns depend on the heart rate, hence the PPG sensors can be other modes for measurement of heart rate, irregularities in the heartbeat thus the variability of heart rate. Developments in smartphone technology are also used for heart rate measurements, were the flashlight in the phone acts as a PPG sensor [10;34;35-37].

3.2 Device for Respiration Rate Measurement

Respiration rate measurement is another vital physiological parameter to measure during the epidemic COVID-19. Acute respiratory distress syndrome, pneumonia, and throat pain are the symptoms for critical patients. Extensive research is in progress for the development of non-conduct devices for respiration rate measurement using imaging sensors [38], Doppler radar [33], depth cameras [39] and thermal cameras [40-41].

3.2.1Dual-Mode Imaging System using thermal and visible sensors

The developments in the recent era in the medical field have promoted the use of thermal imaging considering factors like safety, stability, simple uses, portable, and cost. Thermal imaging-based respiration measurement focuses on the nostril and mouth region of the infected because these are only body parts that undergo a periodic heat exchanger between the body and the outside environment [42]. Thermal imaging technology is used to measure the respiration rate for people wearing masks need to be considered as the pandemic COVID-19 is highly infectious. Experimental studies with dual-mode imaging systems using visible light and infrared light sensing technology are reported [42]. They had developed an imaging system with a thermal camera coupled with visible imaging for automatic recognition of the face and facial tissue in thermal images. **Figure 4** manifest the experimental setup for the non-conduct mode for measuring the respiration rate. The components are a fixed thermal camera with 17µm pixel pitch, an RBG camera with resolution 640×480 is placed parallel to the thermal camera for better resolution for face scanning. The cameras are connected to a computer with customized image, acquisition software is implemented to generate two trigger signals for simultaneous acquisition of thermal and visible videos and analyzed using the MATLAB® R2014a.

3.3 Device for Blood Pressure Measurement

Blood Pressure (BP) is one of the important physiological parameters required for ill patients. Diagnostic and therapeutic treatments given to the patient are based on BP value. This value is often needed for continuous blood pressure monitoring to establish

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or reassess the patients' health. Periodic variations in BP fall between two values one is the systolic value (SP) and the other is the diastolic value (DP). The first value (SP) is the maximum and the other value is the minimum. Variations in the blood pressure systolic value are less than 90 mmHg it is causes reduced peripheral blood flow in blood veins. If the systolic value of blood pressure is more than 140 mmHg there is a high risk for rupture of blood vessels. High blood pressure rupture can cause damage to various human organs [43,44]. Systolic (SP), diastolic (DP), and mean (MP) arterial blood pressure parameters are derived based on various measuring equipment. The standard values of blood pressure are based on different physical events the patient is undergone. The blood pressure measurement using the non-invasive technique is presented in very infancy and is commonly used in intensive care unit therapies. The patients with hypertension are very critical during the COVID -19 pandemic. The advantages and disadvantages of the non-invasive and continuous BP measurements illustrated in the previous literatures [43-45].

3.4 Device for Blood Glucose Measurement

Blood glucose monitoring methods are ever-increasing due to huge demand around the globe which are invasive, painful and time-consuming. The non-invasive glucose monitoring technology overcomes these limitations of invasive methods for the analysis of blood glucose. The development of the non-invasive device for glucose measurement is the need of the hour with the pandemic like COVID-19. Glucose levels in the blood can be estimated from blood directly, plasma of the blood, or blood serum samples using enzymatic and hexokinase methods. Both present a high degree of accuracy, specificity and minimum cross-reaction. The enzymatic methods are preferred over the other, which is attributed to its ease of use, simplicity and economically viable.

The non-invasive technologies for blood glucose detection are optical-based, thermal-based, electrical-based and nanotechnology-based technologies. These technologies are accurate, economical, easy to use and do not depend on body fluids for detection. Optical based blood glucose measurement techniques work based on the infrared spectrum, and these have advantages of the reflection, absorption, and scattering properties of light. These properties are utilized to estimate the glucose level in blood. The heat generation property of the glucose molecule is used to detect the glucose levels in blood using thermal methods. Electric methods utilize the dielectric property of the glucose at low frequencies using a small amount of electromagnetic radiation or ultrasound. The novel nanotechnology methods are in very infancy stages which utilizes the fluorescence in a combination of the optical method [46,47].

3.5 Recently Developed Devices

Diverse devices are commercially available for measuring the vital parameters like heart rate, respiration rate, blood pressure and blood glucose. Table 1, depicts the details of the recently developed devices for vital parameter monitoring. Wearable, portable, and remote monitoring devices are gaining importance due to its versatility, ease in use, fast response, self-monitoring and remote monitoring. The Bio-beat remote patient monitoring platform is one of the FDA approved devices for vital signs in real-time using wireless, non-invasive, medical-grade technology.

4. Applications of E-Health Devices

Applicability of the health devices based on visible light sensing, infrared-based sensing and combination are discussed. The important physiological parameter like heart rate, heart variability, blood pressure, and reparation rate are measured using visible sensing

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systems and their combination with IR sensing. The experimental findings using visible and IR sensing technologies for heart rate, respiration rate, blood glucose level, and blood pressure are discussed in this section of the chapter.

4.1 Heart rate monitoring

VLS-based system developed by Abuella & Ekin, 2020 used the Lambertian model to apprehend the effect of diverse variables and constraints [21]. The distance between the light source and detector is the most important parameter because the power intensity of the received signal at the receiver depends on the distance between the light source and detector. They are proportionally related based on the Lambertian model. Figure 5 demonstrates the intensity of signal variation when the patient inhales and exhales during the testing. The patient's chest expands when he inhales and gets closer to the device and high-power signals are received [21]. When the patient exhales the chest contracts and gets farther away from the device reflecting low power signals. Apart from this, we should note that the value of the distance between the light source and the receiver depends on the age, gender and health condition of the patient. Rates for breathing and heartbeats are extracted using Fourier transform algorithms.

4.2 Respiration rate monitoring

During the experimental findings by M.-H. Hu *et.al.*,2017 videos were captured with a rate of 30 frames per second. The variations in breathing for different patient positions conditions were recorded [40]. Accuracy of Face and Facial tissue was ensured using the Viola-Jones algorithm were integrated the biological characteristics into the custom cascade classifier. This yielded the superior classifiers for detecting face, nose, and mouth with classification accuracies are reported. Figure 6 shows how to further screen the mouth and noise region are carried out using the Viola-Jones algorithm. Figure 7 depicts the breathing signature processing interface for a dual mode imagining system for validating the experimental readings of the device an algorithm used for breathing rate measurement. Similar experimental studies are reported by Jiang *et.al.*, 2020 considers the use of forwarding looking infrared (FLIR) thermal camera attached to a smartphone android device for screening the patients which are portable, feasible, simple, and instant analysis can be carried out [48]. FLIR thermal camera has two cameras namely RGB and thermal-based cameras for face scanning and recording the face videos. Based on the image data from the thermal camera the temperature variations of the nostril and forehead are estimated in time series to differentiate the body temperature and breathing data. Breathing data can predict the respiration rate and breathing pattern of the patient with or without a facemask. Patients with facemasks will be scanned using the two parallel FLIR cameras and the specific marked region as scanned using RBG cameras initially and latter face images are used to extract the features of different scales using the Gaussian pyramid algorithms [2, 48].

4.3 Blood Pressure Monitoring

Blood pressure is measured non-invasively cuff-based using either oscillometer or auscultatory techniques. Higher pressure and lower pressure ranges are measured based on the arms movement in both cases. The auscultatory method is based on heeding to Korotkoff's sounds under the cuff, which appear when the cuff pressure equal to the SP and fades when the remaining pressure equal to DP. There are other novel methods for non-invasive measurement of blood pressure namely, Tonometry, Volume Clamp, Pulse wave velocity, Pulse transit [43-45,49].

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4.4 Blood Glucose Monitoring

There are many non-invasive blood glucose measurement methods namely. Surface Plasmon Resonance (SPR), Fluorescence Technology, Thermal emission spectroscopy, electromagnetic sensing are some of the glucose monitoring methods. Surface Plasmon Resonance (SPR) method uses the electromagnetic field radiations on a thin layer of chemically inert metal surface or conductive material. These electromagnetic field radiations result in the formation of surface Plasmon polaritons (SPPs) on these metals or conducting materials. These SPPs are coherent charge-density waves and highly sensitive to a small change of glucose concentration [47]. Technology innovation in Nanotechnology has let the way to develop SPR sensors capable of detecting minimal concentration ranges in the Pico range are in progress.

5. Conclusions

Visible light and IR sensing technology are gaining importance to develop non-contact medical devices for health monitoring. The development of non-contact medical devices is vital for the detection, monitoring, and treatment of highly infectious pandemic like COVID-19. This review deliberated about sensor integration, non-contact health devices, based on visible light, and Near-Infrared (IR) sensing technology. The future of detection and diagnosis is strongly dependent on the integration of biomedical sensors for developing various monitoring devices which are non-contact, cost-effective, simple, and ease in use, self-monitored, and biocompatible.

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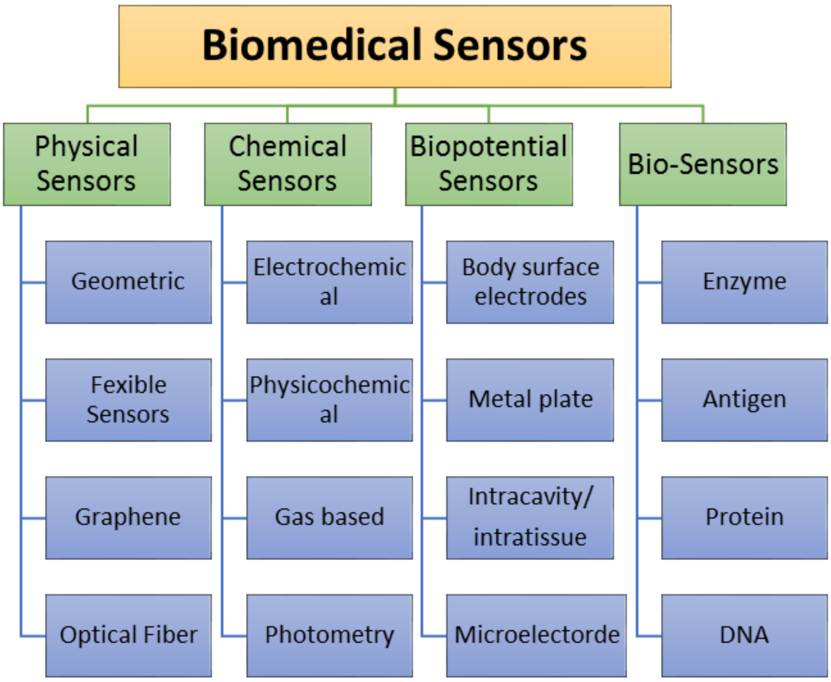

Figure 1: Classification of the bio-medical sensors

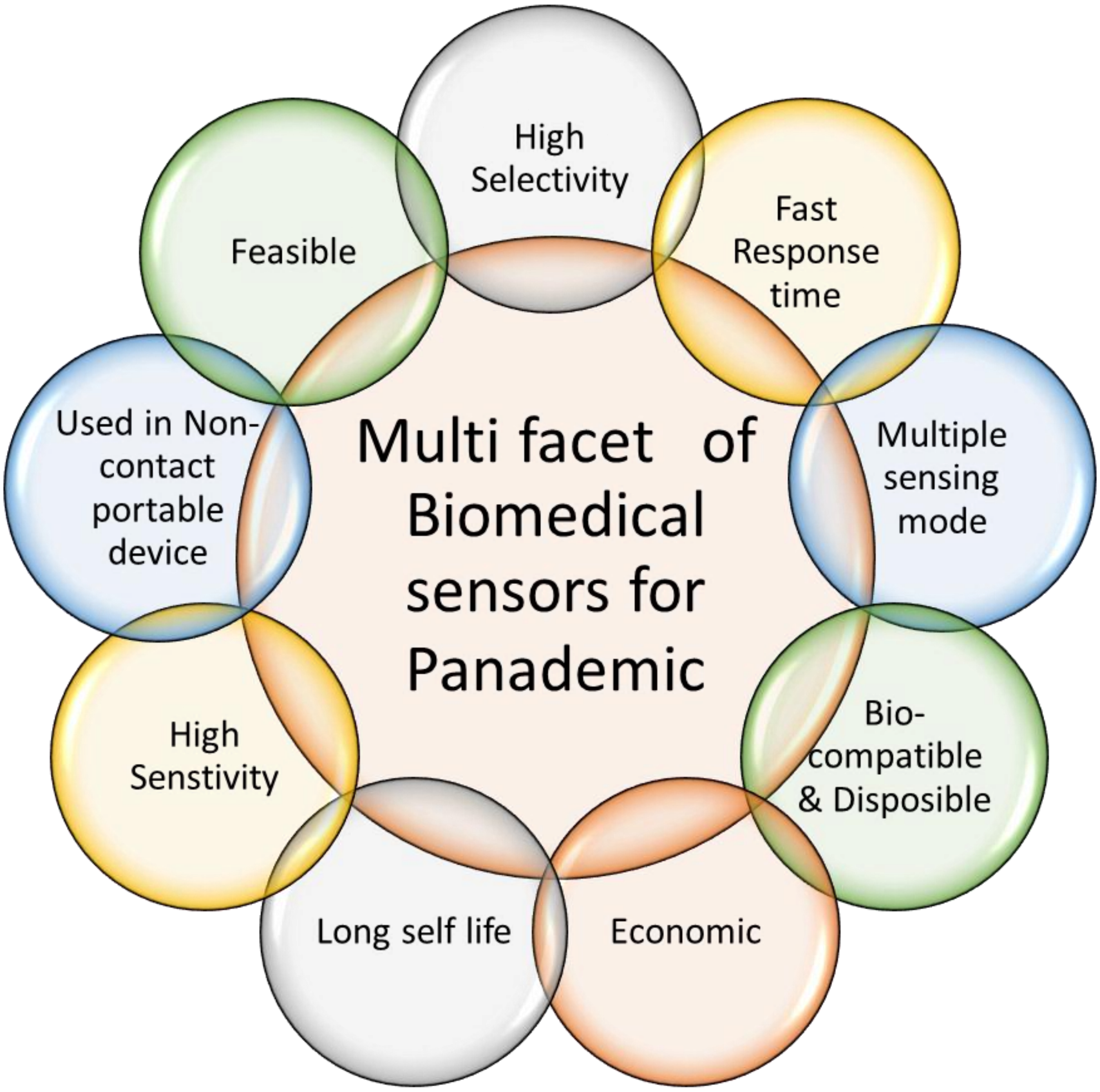

Figure 2: Features of biomedical sensors for effective use in pandemics

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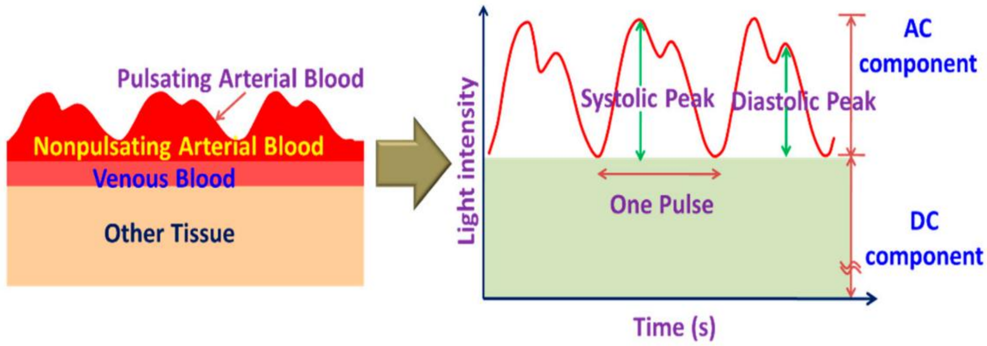

Figure 3: Illustration of Photoplethysmograph (PPG) signal obtained from the pulsatile flow of blood volume (Reproduced from Sensors, MDPI, open source, 2019, 19(9), 2164; https://doi.org/10.3390/s19092164).

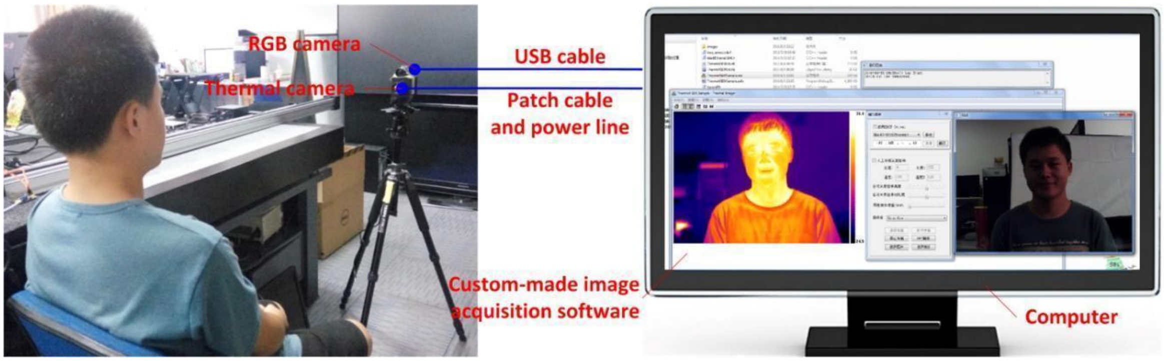

Figure 4: Schematic picture of experimental setup for Dual-Mode Imaging System (Reproduced from Journal of Biomedical Optics, open source 22 (2017) 036006. https://doi.org/10.1117/1.JBO.22.3.036006)

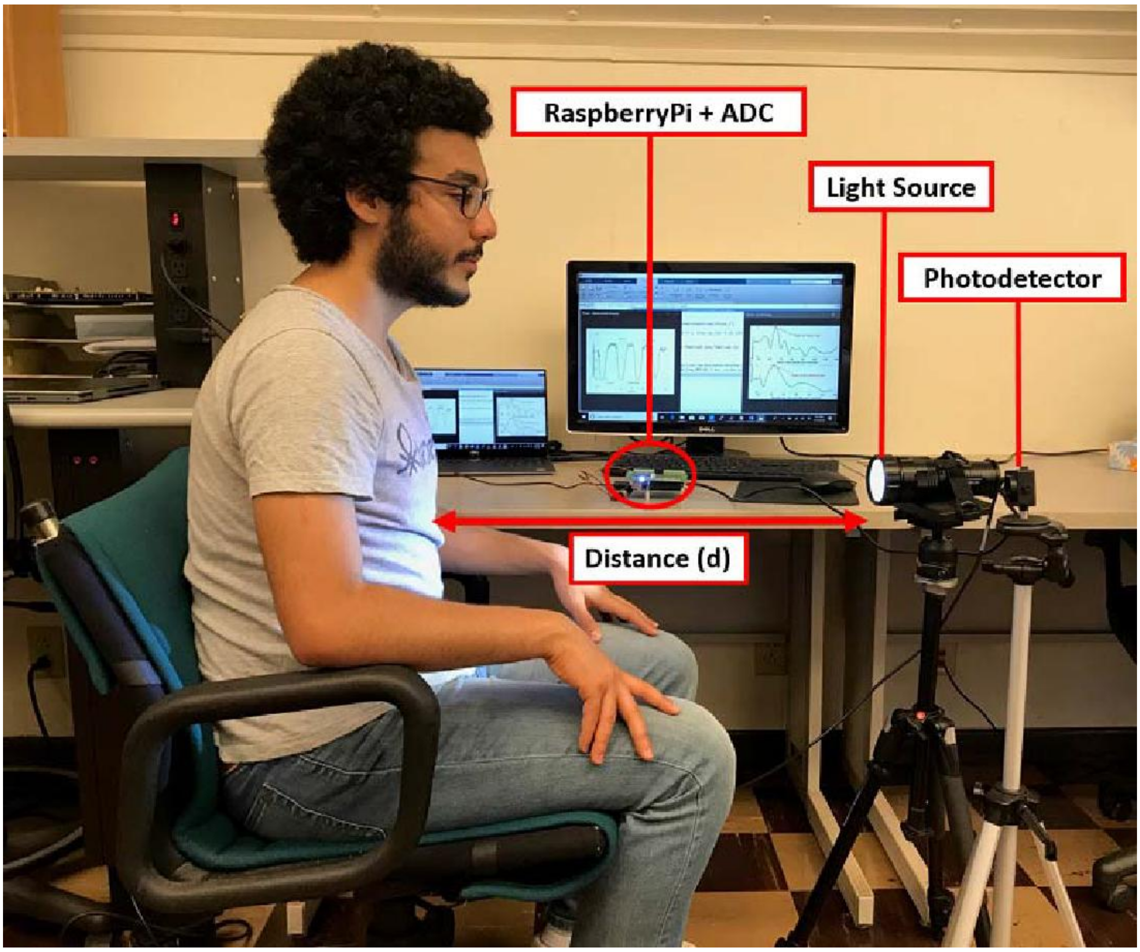

Figure 5: VLS-based non-contact vital signs monitoring system (sitting scenario) (Reproduced with permission from *IEEE Sensors Journal*, vol. 20, no. 7, pp. 3859-3870, April, 2020, doi: 10.1109/JSEN.2019.2960194)

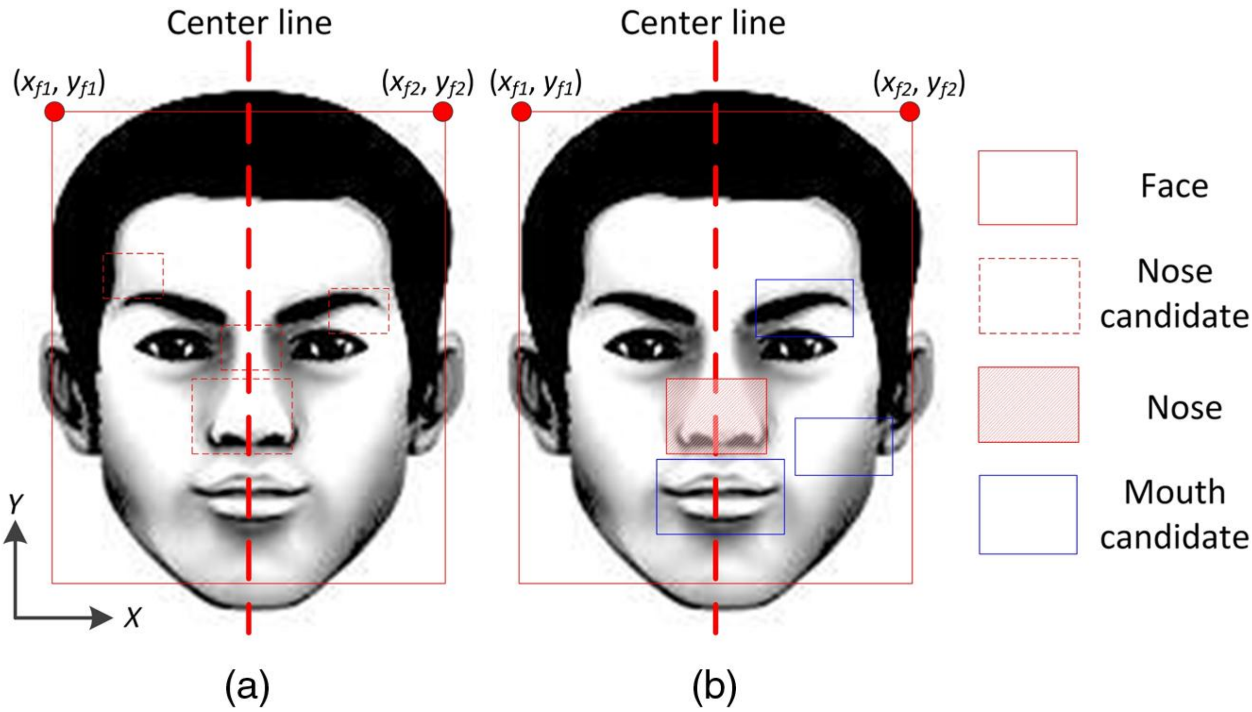

Figure 6: Screening of (a) Nose and (b) Mouth Region (Reproduced with permission from Journal of Biomedical Optics, open source 22 (2017) 036006. https://doi.org/10.1117/1.JBO.22.3.036006)

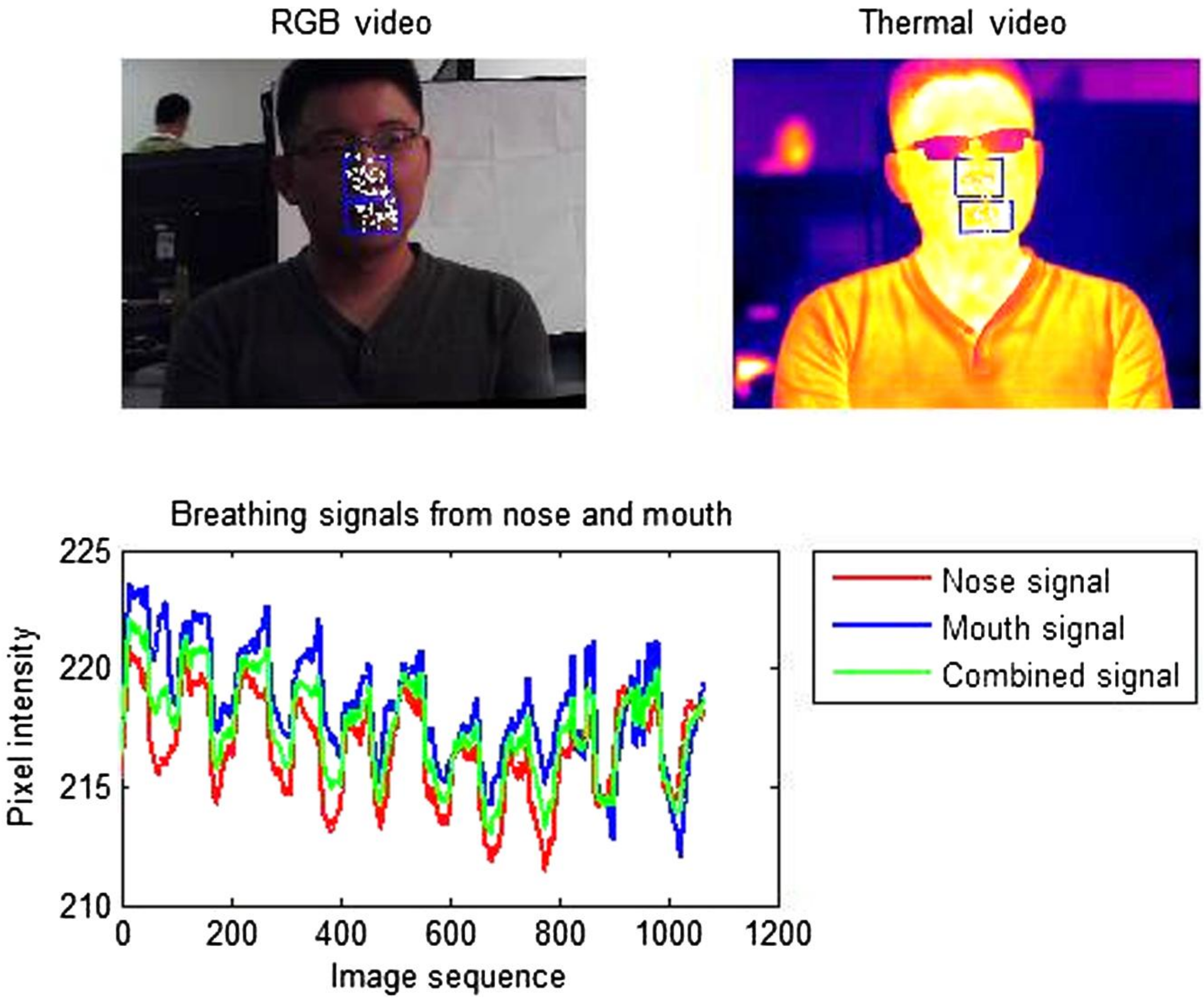

Figure 7: Breathing signature processing interface for dual-mode imaging system (Reproduced from Journal of Biomedical Optics, open source 22 (2017) 036006. https://doi.org/10.1117/1.JBO.22.3.036006)

Table 1: Commercially available Non-invasive devices

Vitals to be Measured	Commercial Name	Manufacturer	Reference/Website
Heart Rate	CorSense®	M/s.Elite HRV	https://elitehrv.com/
	fenix®, vivosport®, Forerunner®	M/s.Garmin	https://www.garmin.com/
	Moyo Fetal Heart Rate Monitor	M/s.Laerdal	https://www.laerdal.com/
	The HeartCheck™ Palm, The HeartCheck™ ECG PEN, BodiMetrics™, VitalsRX™, The HeartCheck™ CardiBeat	M/s.CardioComm Solutions, Inc.	https://www.theheartcheck.com/
	Zio XT	M/s Irhythmtech	https://www.irhythmtech.com/
	CAM PATCH	M/s Bardydx	https://www.bardydx.com/
Blood Pressure	VitalPatch®	M/s. Vitalconnect	https://vitalconnect.com/
	BPM Core	M/s. Withings	https://www.withings.com/
	Biobeat's smartwatch	M/s Biobeat	https://www.bio-beat.com/
Blood Glucose	The iGlucose® System	M/s.Smart Meter LLC	https://www.smartmetercorporation.com/
	Ipen	M/s.Companion Medical	https://www.companionmedical.com/
	TRUE METRIX®	M/s. Trividiahealth	https://www.trividiahealth.com/
Respiratory rate	ChARM	M/s.Philips India Limited.	https://www.engineeringforchange.org/
	Biovitals Sentinel®	M/s.Biofourmis	https://www.biofourmis.com/
	VitalPatch®	M/s. Vitalconnect	https://vitalconnect.com/

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