Analysis of Heart Beat Rate through Video Imaging Techniques

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***Abstract*—Health is the condition of being free from disease or injury either in physically or mentally. To provide a general state of health, analysis of physiological parameters such as heart beat rate, blood pressure, respiratory rate, hemoglobin concentration and etc. are playing an important part. Among these physiological parameters, heart beat rate is the most essential indicator of people's health state because it is the heart rhythms to circulate the blood flow in the human body. Hence, in clinical diagnosis or for the patient in an intensive care unit, heart beat rate is the parameter that must be recorded and examined. The standard equipment like stethoscope, electrocardiogram, pulse oximetry are normally used for measuring heart beat rate but those equipment required to contact sensors to the human skin. In order to overcome the discomforts caused by the long period attachment of sensors and difficulties faced by patients who have skin damages, this research proposed a noncontact technique to measure heart beat rate through video imaging captured by an ordinary RGB camera. The acquired results from video imaging techniques are achieved more than 90% in accuracy by comparing with the results obtained through biomedical toolkit of LabVIEW. The developed techniques are attractive and suitable for regularly health care monitoring purposes due to its contactless, low cost, convenience, multiple people assessments and continuous benefits.**

***Index Terms*—Health; Heart Beat Rate; Video Imaging; Noncontact; LabVIEW.**

I. INTRODUCTION

Health is indispensable to everyone. Besides, it also makes a great contribution to economic progress and development of a country. Hence, it is the most precious wealth in this world. As mentioned in World Health Organization (WHO) [1], health is defined as a state of completely well-being either in physically or mentally. In order to perform a health diagnosis or monitor a person's health status, physiological parameters such as heart beat rate or pulse, blood pressure, respiratory rate and hemoglobin concentration are vital to be measured and recorded. Among these physiological parameters, heart beat rate is one of the most essential parameters to begin the health diagnosis or used to monitor a person's health status. In ancient medicine, the physicians used the arterial pulse to diagnose certain sickness. According to Ghasemzadeh and Zafari [2], ancient Indian and Chinese physicians judged the disease based on the beating pulse and respiration by placing the hand on the patient's wrist. As the technologies being developed, Mannapperuma *et al*. [3] mentioned that the heart beat rate could be measured directly using equipment like stethoscope, electrocardiogram (ECG) or pulse oximetry. Roguin [4] stated that the first stethoscope has been designed in the year 1816 by Rene Theophile Hyacinthe Laennec to hear the sounds produced by the heart and lung. Based on the rhythm of the heart beat, physicians can predict the person's health level. Until today, stethoscope is still widely used by the doctors and physicians. Although hand or stethoscope can be used to measure heart beat rate but it is only suitable to be used for clinical diagnosis, which is short-term measurement.

Continuous measurements of physiological parameters are the common feature for critically ill patients in intensive care unit (ICU). Thus, equipment like electrocardiogram (ECG) and pulse oximetry had been developed for continuous physiological monitoring. ECG is a well-developed technique for observing the electric activity of the heart by placing the electrodes on specific human anatomical. Meanwhile, pulse oximetry is a non-invasive device that monitors the oxygen saturation level, pressure and flow rate of a subject's blood by clipping the spring-loaded clamp on the earlobe or fingertip to measure the intensities variations of red and infrared light that caused by the absorbance of the hemoglobin in blood through a photo detector. Changes in volume of arterial blood flow between the light sources and the photo detector will provide significant information about physiological parameters. Although ECG and pulse oximetry are promising tools in clinical applications but they have several limitations respectively. Among the limitations, they shared the same main drawback, which is the sensor need to be contacted to human skin. These contact sensing methods are discomfort and torture the subjects especially for those who with skin damages. Therefore, the researchers have been incited to study the interaction between tissue optics and physiology for obtaining the physiological parameters in a noncontact manner. Although noncontact techniques may not be able to deliver bio potential that ECG offers, at least these contact-free techniques are able for long period continuously monitoring of physiological parameters by obtaining them from subjects comfortably.

According to Filadelfi *et al*. [5], all vertebrates exhibit morphological color change, which depends on quantitative changes in the pigments. Pigment is a cell that has a specific color that can be found in human skin, hair and eye. Thus, every one of us has different color of skin, hair and eye due to the amount of pigmentations is varied between individual.

From Nielsen *et al*.'s [6] study, human health state is strongly influenced by solar radiation. These interactions relevant to health are mainly happened in human skin because it is the most conspicuous and largest body component. The slight changes of the skin structure and pigments concentration can produce rich skin color variation when illuminated by a light source. In this circumstance, the optics of human skin is of the utmost importance and it can provide valuable information about human health. Pigments in skin that are sensitive to optics are melanin, hemoglobin and carotene. According to Igarashi *et al*. [7], the concentration of carotene is much lesser than melanin and hemoglobin in the skin structure hence optics properties of carotene in the skin can be excluded.

From Liu and Zerubia's study [8], the molar absorption coefficient of melanin and hemoglobin varies with wavelength. The study shows that hemoglobin is correlated with hemodynamic and greatly absorbed green color wavelength. Hence green color channel detected by ordinary RGB camera is suitable to be used for measuring heart beat rate. In 2010, Poh *et al*. [9] had developed a robust method for measuring the cardiac pulse using video imaging and blind source separation (BSS) techniques. The purpose of BSS technique implementation is for removing noise in captured physiological signals. BSS refers as the process that able to recover the signal sources from a set of mixed observed output but without information about the mixing process. The BSS technique that implemented in the authors' research is independent component analysis (ICA). According to Poh *et al*. findings, the authors also proved that green color channel provides the greatest sensitivity to blood pulsations if compared to red and blue color channels. The authors show a good start to the researchers about the possibility to remotely assess the physiological parameters from human skin surface. In 2011, Lewandowska *et al*. [10] verified Poh *et al*.'s concept by defining three independent linear combinations of the RGB color channels with another BSS technique which is principal component analysis (PCA). The authors show that PCA can reduce the computational complexity of the ICA while maintain the accuracy in determining the heart beat rate through video imaging. In the same year, Poh *et al*. [11] also improved the method proposed in 2010 by adding temporal filters before and after applying ICA. The results obtained by the improved method are promising. Although Poh *et al*. and Lewandowska *et al*. used different BSS technique, but both papers used Fast Fourier Transform (FFT) to obtain the power spectral density (PSD) for determining the heart beat rate. Hence in this study, FFT with segmented sliding windows PSD and discrete wavelet transform (DWT) with peak-to-peak calculation are proposed to determine the subject's heart beat rate from video imaging. Besides, the heart beat rate obtained through video imaging is verified to that results obtained from the ECG signals which extracted through LabVIEW biomedical toolkit.

II. Methods for Video Imaging

A. Experimental and Equipment Setup for Video Imaging

In this study, Apple Inc. built-in 720p FaceTime HD camera on a Macbook Pro is used to capture video for heart beat rate analysis. All specimen videos were recorded in RGB color at 30 frames per second (fps) with pixel resolution of 845 × 480 pixels and saved in mp4 format. The duration of each recorded video specimens is 1 minute. 6 participants between the ages of 13-81 years old with 8 sets of data were examined. During the video recording, the participants are requested to sit still and avoid any facial expressions but subtle movements of head positions are acceptable. The participants are seated at a distance approximately 0.5 m in front of the built-in camera for the video recording purpose. The measurements were performed indoor and the light sources are fluorescent lamps that produce visible light. In this study, fluorescent lamps are chosen as the light sources because of its convenient and availability. Furthermore, it able to provide consistent light intensities for reducing the light source intensities variations problems. Besides, the measurements can also be done during night time where there are in absence of the sunlight. The light sources intensities are very important in measuring heart beat rate though video imaging because it could effects the strength of the RGB signals that recorded by the camera sensor. If the video were recorded under extremely dimmed condition, the difficulties in estimating the heart beat rate will be increased due to the RGB signals of the human skin remittance spectra that received by the camera sensors are very weak. This is due to the video recorded under low light intensities condition, the temporal changes of the human skin remittance spectra are not apparent and hardly being detected. Hence, fluorescent light is used in this study to validate the light intensities are sufficient to conduct the experimental data. The platform used for analyzing the recorded video is Matlab-R2013a. According to Tarassenko *et al*. [12], forehead has vascularization, which the blood is supplied from the supra-orbital artery. Besides, forehead is also the most uniform facial feature. Thus, participant's forehead is selected as the region of interest (ROI) to perform the heart beat rate extraction. The ROI of 50 × 20 pixels on the forehead is extracted for further analysis.

B. Preprocessing for Heart Beat Rate Analysis

An image is formed when illumination is reflected to the camera sensors from the target objects. Human skin is an inhomogeneous organ that covering the human body with complex optical properties i.e. reflection, refraction, absorption and scattering properties. It generally consists of four layers (stratum corneum, dermis, epidermis and hypodermis) associate with skin constituents (pigments, vessels, fibers and cells) [13]. The different depth of the layers and pigments in skin structure affects the propagation and absorption of light. According to Baranoski and Krishnaswamy [13], approximately 5-7% of the light incident on the skin surface is reflected back to the environment. The residue light incident will be transmitted into the internal skin layers and internal optical properties will take place. Consequently, pigments found in the skin structure like melanin and hemoglobin can absorb light, the residues of the absorbed light will be re-emitted back to the skin surface. These remittance spectra of the skin surface that consists of the light directly reflected by the skin surface and the in vivo residue light that re-emitted back to the skin surface are recorded by camera. Since skin surface is inhomogeneous, any small movement will cause large changes to the remittance spectra. Thus ROI is used in this study instead of a single pixel point data.

Hemoglobin is strongly absorbed in the green color wavelength, thus green color channel captured by the RGB camera is contained valuable information about the blood volume changes in blood vessels. These blood volume changes will cause the light intensities captured by the camera varies from frame to frame which unobservable by the naked human eye. Based on the measured light intensities, the subject's heart beat rate can be measured. In order to obtain the green color component from the images, the ROI is decomposed in red *(R)*, green *(G)* and blue *(B)* channel individually. Consequently, the pixels of the ROI are averaged and normalized. Since the captured video is in form of RGB, the green color channel is normalized to remove the effects of any intensity variations within the ROI using (1). Equation 1 is used for normalization because of the red, green and blue colors in the RGB color planes are added together in different ratio to form a color cube. The RGB pixel values that obtained from the video imaging are represent the endpoints of a vector in the RGB color space. Hence, the green color channel can be normalized by dividing the green color pixel value detected in the video imaging to the length of the vector in the RGB color space.

$$G_i = \frac{G_i}{\sqrt{(R_i)^2 + (G_i)^2 + (B_i)^2}} \tag{1}$$

The measured normalized signals from green color channel show a trend that must be removed because it can hinder the data for analysis. Thus, detrend function is used to remove the linear trend from the normalized green color values. It helps to focus on analyzing the fluctuations in the data about the trend and it also the preprocessing step usually for Fast Fourier Transform (FFT) processing. After the preprocessing step, BSS technique by ICA is applied for artifacts removal. When the RGB camera recording the video for heart beat rate extraction, the camera sensors collect a mixture of the remittance spectra of the skin together with other sources of fluctuations in light caused by artifacts like motion and fluctuations of the fluorescent lamps. ICA is a technique to separate independent source signals, *S* from a set of recorded signals, *A* that are linearly mixed by a mixing matrix, *M* as shown in (2). ICA able separates the mixture of signal source by maximizing the non-Gaussianity of each RGB signal source [11]. Based on the calculated mixing matrix, *M*, the demixing matrix, *D* can be determined by using (3). Once demixing matrix, *D* is calculated, the signals sources, *S* can be separated to independent components from the mixtures through (4). Hence, the purpose of ICA is used to calculate the demixing matrix, *D* by just knowing only recorded signals, *A* which is the RGB pixel values.

$$A = M \times S \tag{2}$$

$$D = M^{-1} \tag{3}$$

$$S = D \times A \tag{4}$$

After the signal sources are independently separated, the green color channel will undergo fourth-order butterworth filter with cutoff frequencies set at [0.7, 4] Hz to further attenuate signal noise. The cutoff frequencies were set at [0.7, 4] Hz because the heart beat rate for a normal person is within the range of 42 – 240 bpm. After the signals are filtered, FFT with PSD and DWT with peak to peak calculation are used to obtain the subject's heart beat rate.

C. *Fast Fourier Transform with Power Spectral Density*

FFT is applied on the filtered green color channel to obtain the PSD. This is because the cardiac pulse frequency was computed based on the highest power of the spectral density. According to Liu *et al*. [14], FFT is commonly applied because of its simplicity and ability to deliver fundamental physiological information easily and directly. In this study, the filtered green color channel is segmented using a 6 seconds sliding window with the time interval of 0.5 seconds. Figure 1 indicates each segmented 6 seconds sliding window will undergo FFT transform to obtain the PSD.

Once the PSD of each 6 seconds sliding window is obtained, the frequency indicates the highest peak of the PSD is used to measure beat per minute (bpm) via (5) where *SWBPM* is the heart beat rate of the current sliding window and *k* is the number of segmented sliding windows. Since heart beat rate is measured based on the number of beat per minute, and hence the highest peak of the frequency, *MF* is required to multiply by 60 as shown in (5). When the recorded 60 seconds video is finished processed, the mean value of heart beat rate is calculated using (6).

$$SWBPM(k) = MF(k) \times 60 \tag{5}$$

$$BPM\_PSD = \frac{1}{N}\sum_{k=1}^{N} SWBPM(k) \tag{6}$$

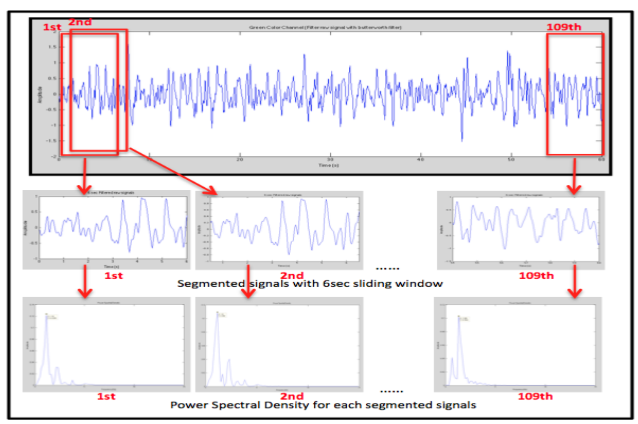


Figure 1: The Procedure to extract subject's heart beat rate

D. *Discrete Wavelet Transform with Peak-to-Peak Calculation*

Biomedical signals such as ECG, and electroencephalogram (EEG) are kind of signals that measured from a specific part of the human body and have a non-stationary behavior, which means the behavior is instantaneous vary in time. According to Ballesteros *et al*. [15], DWT is widely implemented in multi-scale processing of biomedical signals because it can represent both time and frequency of the signal characteristics. In DWT analysis, the redundancy in the green color signals can be removed and a high quality of signals can be reproduced using inverse discrete wavelet transform (iDWT) because the wavelet coefficients are not repeated when the raw signals are decomposed. Figure 2 shows the general procedure of decomposition and reconstruction of a signal based on DWT where *S* is signals, *l* is low pass filter, *h* is high pass filter, *DS* is down sampling, *US* is up sampling, A_1 is level one approximated signal, D_1 is level one detailed signal. The ability of DWT to filter the signals with low distortion shows a good agreement for noise removal. Thus, DWT is implemented to analyze the time-frequency characteristics of the green color channel signals associates with the heart beat rate due to its ability in extracting the exact features from recorded signals. Figure 3 indicates the signals before and after DWT decomposition and reconstruction. After the signals are reconstructed, the heart beat rate of the subject's is measured by calculating the peak to peak distance, *PDis(i)* of the signals as shown in Figure 3 which indicated by red color scale. The *PDis(i)* in unit second is obtained using (7) where *P* is the maximum peak in time. Next, average of the peak to peak distance, $PDis_{avg}$ is calculated and substituted in (8) to obtain the mean value of heart beat rate in 60 seconds. Since the RGB signals obtained through noncontact video imaging technique are much weaker and contaminate more noises than those contact methods, therefore the peak to peak distance of the denoised DWT waveform need to be averaged over 60 seconds in this study for increasing the accuracy of the heart beat rate estimation. According to Becker [16], heart beat rate can be obtained through measure the time between the peak to peak of the RR-interval in the ECG waveform. Therefore, the proposed contactless method to estimate the heart beat rate from the video imaging DWT waveform is based on the concept applied to the heart beat rate measurement through the contact manner that is ECG waveform by using (8).

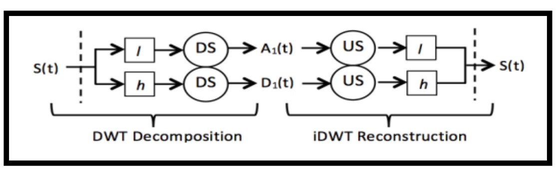


Figure 2: The general procedure of DWT decomposition and reconstruction signal

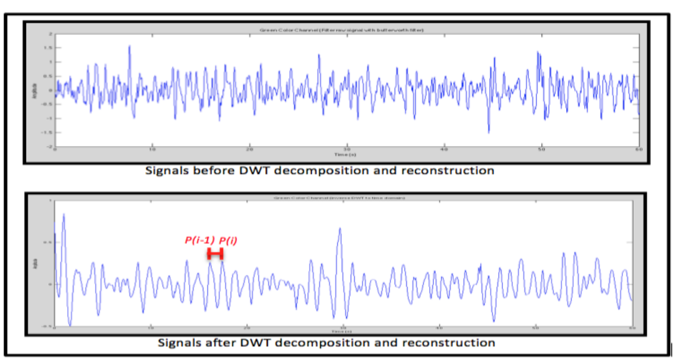


Figure 3: Green color channel signals before and after DWT decomposition and reconstruction

$$PDis(i) = P(i) - P(i-1) \tag{7}$$

$$BPM = \frac{60}{PDis_{avg}} \tag{8}$$

III. METHODS FOR LABVIEW BIOMEDICAL TOOLKIT

ECG is a technique of recording the electrical activities of the heart using electrodes. From the ECG signals, physicians can evaluate conditions of the subject's heart to perform further diagnosis or monitoring. Standard placements of the electrodes to measure heart beat rate is based on Einthoven's triangle as shown in Figure 4 where RA, LA and LL, is the right arm, left arm and left leg respectively. Bipolar limb leads of Lead I, II and III are shown in Figure 4. The leads are used to measure the potential difference generated by heart contraction through two electrodes. The potential difference between the leads can be determined by using LabVIEW biomedical toolkit. Additionally, biomedical toolkit associated with advanced signal processing and digital filter toolkit can assist the users to obtain and process the ECG readings more correctly. According to Beasley [17], Lead II is most commonly used for heart monitoring, thus Lead II is used to obtain subject's heart beat rate for verifying the results obtained through video imaging techniques. Lead II signals are acquired through NI USB-6281 data acquisition (DAQ) device with lead wires and electrodes. Figure 5 shows the equipment and connection used for heart beat rate extraction and calculation. Figure 6 indicates the ECG result and mean of 60 seconds heart beat rate are obtained from LabVIEW.

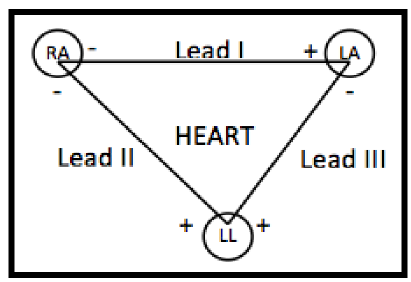


Figure 4: Einthoven's triangle

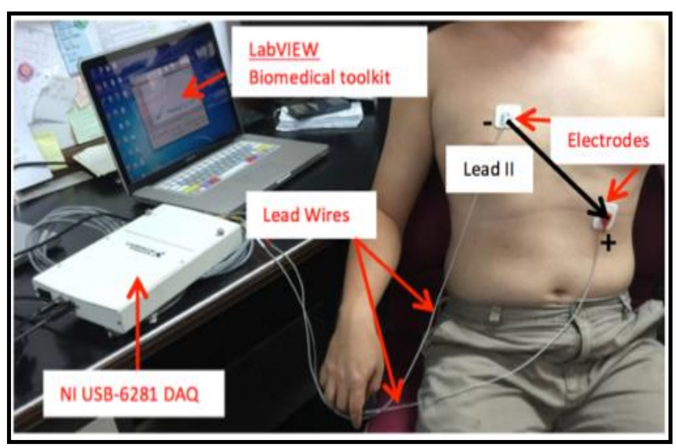
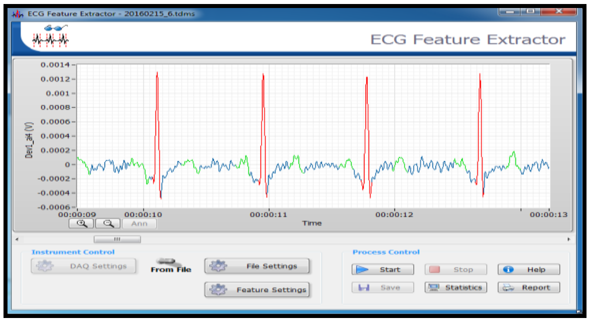


Figure 5: LabVIEW setup to acquire and process heart beat rate



ECG waveform from LabVIEW Biomedical Toolkit

Statistics	
Total number of beats	70
Heart rate mean	68 bpm
Heart rate std.	2.6 bpm
QRS width mean	73 ms
QRS width std.	9.5 ms
QRS amplitude mean	0.0043 V
QRS amplitude std.	0.0003 V
PR interval mean	169 ms
PR interval std.	4.29 ms
QT interval mean	372 ms
QT interval std.	20.6 ms
Iso level mean	0.0041 V
Iso level std.	0.0012 V

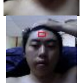
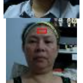
ECG features extracted from LabVIEW Biomedical Toolkit

Figure 6: ECG signals and mean of 60 seconds heart beat rate is extracted from LabVIEW Biomedical Toolkit

IV. RESULTS AND DISCUSSIONS

Table 1 shows eight sets data of mean heart beat rate obtained from six participants. In this study, the heart beat rate obtained from LabVIEW is used as a reference to verify the results obtained through image processing techniques, i.e. FFT with PSD and DWT with peak to peak calculation because LabVIEW provides a convenient and reliable biomedical toolkit for ECG extraction and analysis. Table 1 shows that video imaging techniques are very potential to replace the contact methods in determining heart beat rate because the percentage of accuracy is achieved over 90% in all subjects with different gender and a wide range of ages (13-81 years old). The results show that 81 years old subject has the lowest percentage of accuracy in both image processing techniques because of the wrinkles on the forehead. Although the subjects are requested to sit still but subtle head movement is still unavoidable. Thus, intensities of the remittance spectra is easily changed by these wrinkles and makes the detection harder. Although the percentage of accuracy obtained from 81 years old subject is lowest, but the accuracy is still very convincing in achieving 90.6%. Since perfect accuracy is not always required in heart beat rate counting, thus difference in 5 bpm is still acceptable for monitoring purposes. From this study, it shows that the heart beat rate monitoring is not only can be done through contact methods, but it can also be achieved through noncontact method which is video imaging.

Table 1
Subject's heart beat rate obtained through video imaging techniques is verified by the results obtained from LabVIEW Biomedical Toolkit

Subject	Age	Gender	LabVIEW (Reference BPM)	Fast Fourier Transform with Power Spectral Density			Discrete Wavelet Transform with Peak to Peak Calculation		
				BPM	Difference (BPM)	Accuracy (%)	BPM	Difference (BPM)	Accuracy (%)
	13	Female	86	86	0	100%	85	1	98.8%
	31	Male	77	75	2	97.4%	78	1	98.7%
	31	Male	74	73	1	98.6%	72	2	97.3%
	31	Male	74	77	3	95.9%	76	2	97.3%
	31	Female	80	80	0	100%	76	4	95%
	52	Female	68	68	0	100%	70	2	97.1%
	57	Male	86	83	3	96.5%	85	1	98.8%
	81	Female	64	70	6	90.6%	67	3	95.3%

V. CONCLUSION

In this study, noncontact video imaging techniques are presented to estimate the heart beat rate and the results are compared to results obtained through LabVIEW biomedical toolkit. LabVIEW biomedical toolkit with implemented ECG extractor feature is a convenient and reliable tool for heart beat rate acquiring and extraction. From the results, it has been demonstrated that the heart beat rate of the subjects can be estimated with good accuracy (>90%) in video imaging using a ROI of forehead. Thus, video imaging is potential to overcome the constraints in conventional techniques such as the drawbacks in continuous obtaining and monitoring physiological parameters, irritation and discomfort after long period of sensors attachment, limited mobility caused by the wired sensors, single subject assessment and require trained physicians to operate. As a conclusion, the analysis of heart beat rate through video imaging is attractive, potential and worth to be studied for its contactless, low cost, convenience, multiple people assessments and continuous benefits.

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