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Exploiting the Interdependence of Electrocardiography (ECG) with Other Physiological Parameters of Human Body in Remote Monitoring System

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Abstract*: Human body holds physiological parameters like heart rate (HR), respiration rate (RR), temperature, blood glucose level and blood pressure (BP) that indicates the health state. Monitoring these vital signs detect early signs of significant diseases like cardio-vascular and pulmonary which increase the death ratio as 70% of global death and in India it was attributed to 61% as per World Health Organization (WHO) report. With advancement in modern technologies health monitoring is achievable without affecting their regular activities and by making people to be at anywhere, not to be in hospital for long stay. In this paper the relevance between electrocardiography (ECG) and remaining other physiological measures is highlighted which will be incorporated in the design of health monitoring device in near future by revealing its complexity and ensures the high comfortability in accessing the device.

***Keywords*: Physiological parameters, cardio-vascular disease (CVD), electrocardiography (ECG), health monitoring.**

I. INTRODUCTION

Physiological parameters, also known as vital signs estimates the proper functionality of human body, indicates well-being or health status of the person. In general, four parameters like HR, RR, BP and body temperature (BT) are considered as a predominant ones, helps in assessing physical health. These signs are monitored at a regular interval by the medical professional to mine the occurrence or presence of possible diseases and later in recovery process and facts of these are tabulated as table 1.

To quickly decide the illness of the patient based on their vital sign, an early warning score (EWS) is proposed and accounted as one of the medical services from late 1990 by a crew in James Paget Hospital, United Kingdom (UK) [1]. It is clearly stated that cardiac arrest and fall in health occurs as a result of increasing abnormalities in vital sign observed over a period of time. Heart failure is an end product of multiple illnesses that damages the heart and affects its normal functioning [2]. The causes of heart failure and its progression is illustrated in figure 1.

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The BP and problems associated with breathing issues are noted as a sole contributors of heart failure. The predominant signs to be monitored regularly to notify the good heart conditions are BP, RR and HR [3]. Apart from this, the modern life style activities such as eating habits, work culture and bad habits stands as an evidence for other critical health conditions like obesity, diabetes and thyroid disorders, identified in too early ages of the person. Because of this conditions, youngsters are more prone to have heart failure than elders. To alleviate from this issue, arises the need of a handy tool that facilitates self-tracking and management activities to control and maintain their health. Remote patient monitoring is a golden tool, attracted researchers in providing the regular tracking of physical conditions outside the hospital campuses and being engaged in their routine day-to-day activities without any interruptions [4].

Table- I: Significant Physiological Parameters of Human Body

Vital Sign	Description	Common Methodologies	Equipment's in Medical Practice	Region of Interest (ROI)	Normal Range
HR	Heart work rate	• Manual interpretation –Pulse rate • ECG/EKG • Photo plethysmography (PPG)	• Stethoscope • Electro cardiograph machine • Pulse Oximeter	Wrist, Chest, Earlobe, Forehead & Finger	60 to 100 beats per minute
BP	Strength of blood circulation	• Auscultator • Oscillometric	Sphygmoma -nometer & Stethoscope	Arm, Elbow & Wrist	90/60 mm Hg to 120/80 mm Hg
RR	Rate of breath ing	Manual & Equipment interpretation – Chest Rise Count	Stethoscope	Chest	12 to 18 breaths per minute
BT	Ability to manage heat	Equipment interpretation – Temperature	Thermometer	Mouth, Ear, Armpit, Rectum & For head	97.8°F to 99.1° F

The researchers in today's technologies like wireless sensor networks, IoT, Big Data analytics, cloud computing and cyber security, is on the way to promote proactive remote monitoring in very few years. The advantages of remote health monitoring ensures the following.

- Continuous monitoring of health
- Early detection of illness
- Emergency care through non-invasive medical interventions
- Prevents the untimely death ratio
- Proactive medical services
- Reduces the count of hospitalizations

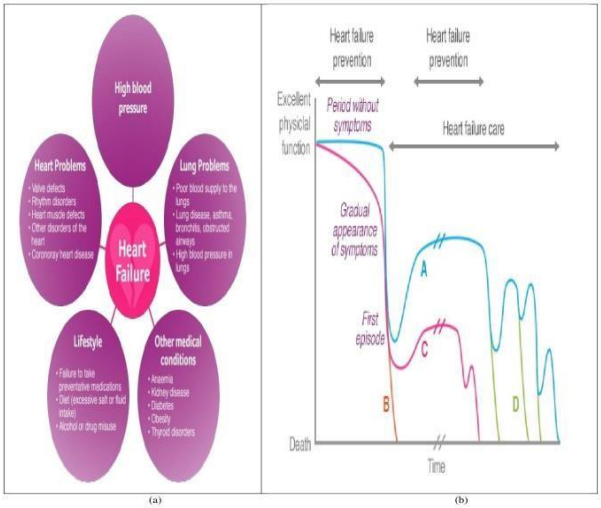


Fig. 1. Facts of Heart Failure presenting a) Possible causes of heart failure b) Development of acute heart failure in correlation with physical function of the body. A shows a good recovery after the first acute episode followed by a stable period. B shows that the first episode is not survived. C shows poor recovery followed by deterioration. D shows ongoing deterioration with intermittent acute episodes and an unpredictable death point. (Source: Cowie et al, 2014)

The transformation of medical service lies in the well design of remote monitoring kit featuring the recent technologies and ensuring the accuracy of medical standard. In addition to that, the kit has to promise the adequate user requirements like affordability, access friendly and comfortability. This paper discusses the key idea to be exploited in the design of building such ambulatory kit with reduced circuitry.

II. MATERIALS AND METHODS

The intensive search was carried out using keywords of list including remote monitoring, physiological parameters, ECG, extraction of other signs from ECG in reputed journals and the filtering process selected the articles contributed by Springer Link, IEEE Link and some Scopus indexed from the year 2005- 2018. No duplicate copies were found, and as result of keen filtration a total 13 documents were considered to conduct review. The entire process is depicted as figure 2.

Further an additive step to collect opinion about recent requirements on remote monitoring system from public and medical experts, a detailed survey was executed via questionnaire.

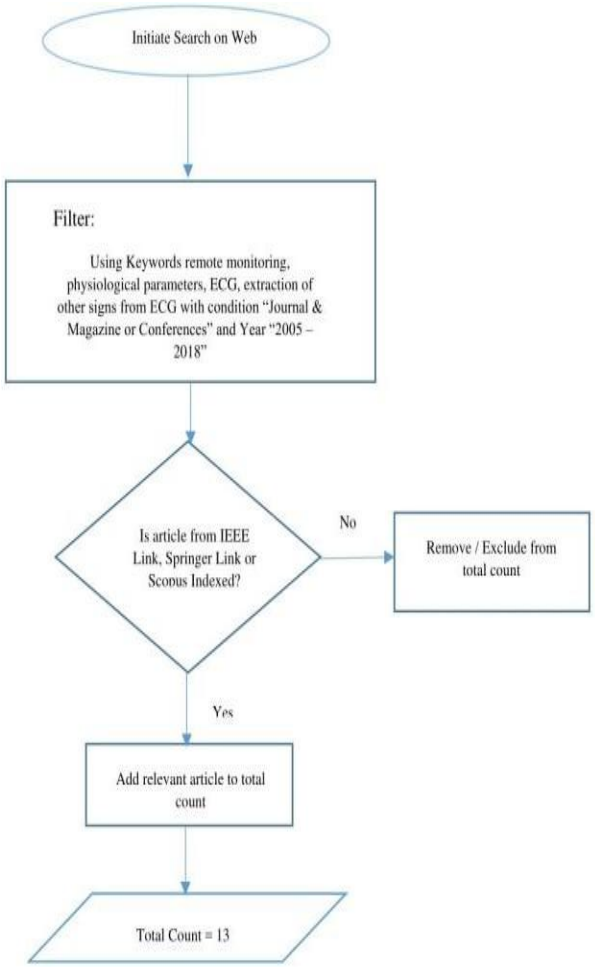


Fig. 2. Process to Extract Relevant Articles of Study

A questionnaire was prepared in the motive of yielding the answers to the following:

- Is there any independence exist in physiological measures?
- Are they satisfied with the existing methodologies to extract the physiological measures?
- Is steady monitoring of vital signs aid in detect significant diseases as early as possible?
- Is there adequate need for remote monitoring kit?
- What are the principal physiological measures to be incorporated in remote monitoring kit?
- Will you belief that proactive disease management achievable with this kit?
- Exercised any of the remote health trackers existing in market?
- Is accuracy compromised in the existing health trackers?

The questionnaire evaluation and observations made from the filtered articles listed in table 2 used as inputs in deriving methodology to design smart remote monitoring.

Table- II: Literature review on acquiring physiological measures of human in assisting remote monitoring

Journal ID	Objective of the Article	Application
1	Benefits of Early Warning Scoring System in detecting critical illness	Used as a protocol to review sick patients with deterioration levels
2	Complete study of causes of heart failure, way to diagnosis and prognosis	Used as a guide to detect and treat acute heart failure
3	Predominant physiological parameters of human body and a design of wearable to monitor the same	Used to monitor the physiological measures securely in the form of wearable
4	Trends and applications in remote patient monitoring	To be used in designing well effective remote monitoring kit
5-9	Association between ECG and BP and method to extract BP from ECG	To be adopted in designing remote monitoring kit as in the form of wearable
10-12	Correlation between ECG and RR	To be used by wearable manufacturers and clinicians
13	Relationship exists between BT, HR and RR	To be utilized in designing real time monitoring device in ambulatory environments

III. RESULTS AND DISCUSSIONS

The observed dependency map with the associated methods to arrive from one another is captured as figure 3 and the details are discussed below.

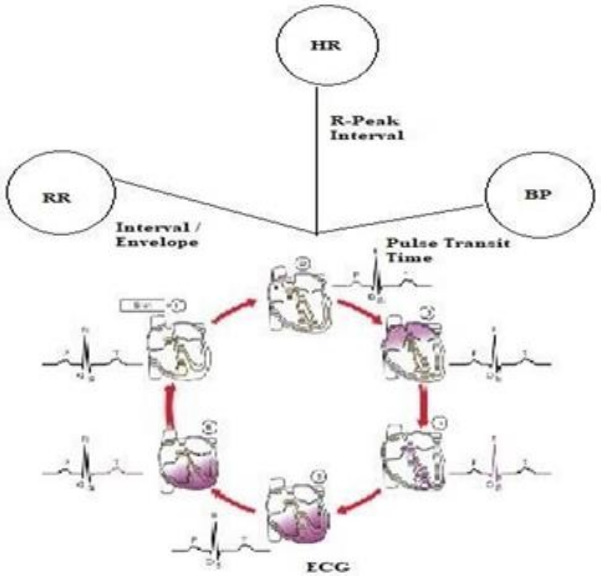
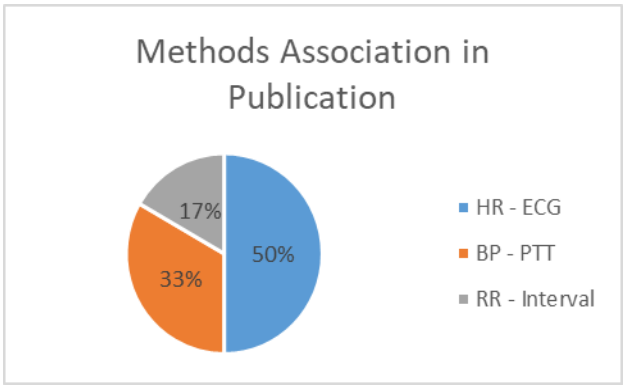
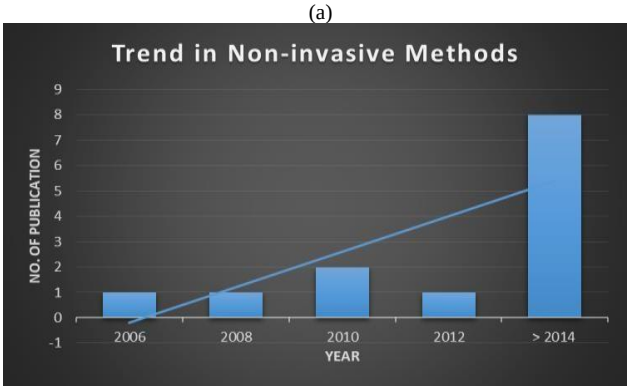


Fig. 3. Dependency Plot between ECG, HR, BP and RR

The growing trend in obtaining the optimal non- invasive methods for remote health monitoring is assessed against the past and upcoming publications and highly associated methods to arrive BP and RR is presented as figure 4.



(a)



(b)

Fig. 4. Result of Scientific Publications presenting a) Growing trend for non-invasive methods in remote monitoring b) Associated methods contribution

A. Linkage Concerning HR and BP

In general, the heart pumps the blood, and the BP indicates the amount of pressure applied while circulating the blood around the body. The rise in heart rate increases the BP and the vice versa holds true. BP usually holds two values; first one is known as systolic BP (SBP) which is the pressure measured when the heart beats and other is called as diastolic BP (DBP) which is the pressure obtained when the heart relaxes. Heart rate can be obtained through many methods. The most commonly assessed methods are ECG and PPG. In PPG, light source like flash and sensor are used and works based on the principle that light entering the body will disseminate in an expectable manner as a result of changes in the blood volume. Through flash, a light shine is made to penetrate into skin and the reflected light which is aligned with our pulse rates are captured through the sensor. Traditionally in clinical laboratories, the cardiac conditions were examined through the method of ECG by placing contact electrodes at various bodily positions from chest to leg. As ECG is accounted as a direct method that measures the electrical signals of heart activity, and ECG based measurements is generally accurate within a couple of milliseconds, making it a highly reliable measure of heart rate. From ECG the heart rate is estimated through the sequence of equations given in 1-3, by obtaining the time interval of consecutive R- peaks, frequency and finally the HR.

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T = t1 – t2 (seconds) (1)
F = 1 / T (HZ) (2)
HR = f * 60 (beats per minute) (3)

Through exploiting the association between HR and BP, the reliability of non-invasive methods are analyzed to measure BP. All those methods works based on pulse transit time (PTT) which is obtained from acquired signals of ECG and PPG as given in figure 5.

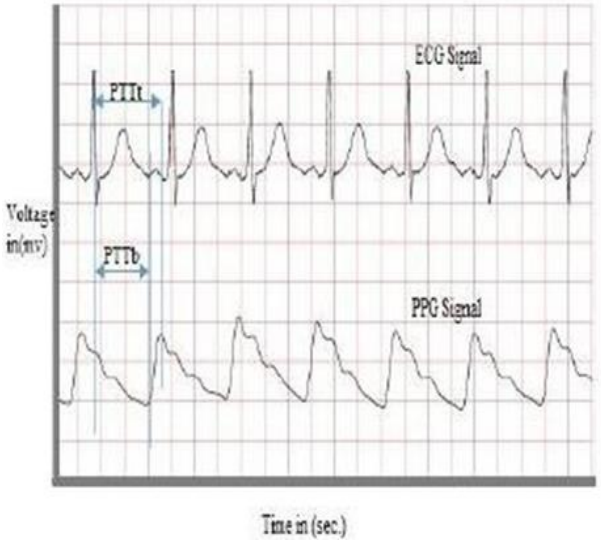

Fig. 5. Acquisition of PTT using ECG and PPG (Source: Sarveshkumar et al, 2015)

PTT is acknowledged as the time exist interval between the pulse wave generation in cardio aortic and its propagation towards artery peripherals. In simple terms, PTT is the difference between the acquisition of pulse arrival time (PAT) to periphery and upon its generation.

PTT = PAT1 – PAT0 (4)

These two points are referred as proximal and distal point. Aligned with figure 4, the presence of R-peak in acquired ECG signal is always marked as a proximal point (PAT0). With reference to PPG, the observed immediate peak or fall is considered as an end signal that results the systolic and diastolic BP respectively PTT bottom (PTTb) and PTT top (PTTt) as per the usage of terms in the mentioned figure [5].

PTTb = SBP &
PTTt = DBP (5)

The end of PTT varied based on methods and sensors used to obtain the pulse wave. With piezoelectric sensors, the peak of the pressure signal of radial artery is seen as an end sign. Furthermore, with magnetic sensor, the peak of Modulated Magnetic Signature of Blood (MMSB) signal is treated as an end signal. Among those methods PPG has high dependency in measuring the BP [6].

The calculation of PTT and estimation of BP is investigated making use of smartphone capabilities like microphone and camera instead of bringing a new equipment. ECG is obtained by recording heart sounds through microphone and PPG is evaluated by photosensitivity in camera [7]. Based on regression model, after the attainment of BP, the SBP and DBP are estimated arriving the correlation with PTT [8]. A novel regression model is built upon training set provided with the SBP and HR as the elements, to estimate the SBP in unspecified subjects [9].

In the current scenario, PTT is the only accepted method to estimate BP invasively without cuff and any explicit instrument in place. Applying statistical techniques like linear regression, the formula for BP estimation is arrived [5-9].

B. Linkage Concerning HR and RR

Similarly breathing pattern impacts the function of the heart. Issues in breathing pattern causes distortions in heart activity. Mason and Laura investigated the reliability of non-invasive estimation RR in their doctoral study at Oxford University. They examined a number of non-invasive respiration monitoring methods including respiratory sinus arrhythmia (RSA), which is the change in heart rate associated with breathing and QRS amplitude modulation and that is the change in amplitude of the ECG associated with breathing. No single method was found to be ideal, and finally Mason and Laura suggested that the fusion of several methods will provide better results [10].

Observing the rate of change in heart activity in correspondence with breathing pattern paves the way for estimating RR invasively. A fundamental step in estimation of RR either from the ECG or PPG is the extraction of a respiratory signal: a signal dominated by respiration. Respiratory signals can be extracted from the ECG and PPG using either feature based (interval) or filter based (envelope) techniques [11]. Based on the process of extraction, further classified into three types namely, baseline wander (BW), amplitude modulation (AM), and frequency modulation (FM).

A method to recognize the respiration cycle lengths from ECG signal extracted from textile electrodes that are attached to a bed sheet was proposed [12]. The result notifies that the proposed method worked well for youngsters within age group of less than 35.

The numerous non-invasive techniques developed so far are recorded in table 3.

The investigation result of the non-invasive methods implemented till the period demonstrated that interval methods performs far better than envelope methods and ECG input signal proves high impact on accuracy of the result. The formula used to estimate the RR from ECG with the usage of interval method is given in equations (6 – 7).

RR = 60 / Δ Peak-Time (breaths per minute) (6)
Δ Peak-Time = p1 – p2 (7)

Where Δ Peak-Time is the interval between two successive peaks respectively p1, p2.

The technical factors input signal, its frequency and measurement site and physiological factors like age and gender to be take into account before electing a good choice of non-invasive method to assess RR. All the methods uses statistical technique such root mean square error (RMSE) to validate the accuracy of estimated RR from the ECG.

Table- III: Derived methods to extract RR from ECG / PPG

Filter Based Methods

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BW	AM	FM
Band-pass filter between plausible respiratory frequencies	The maximum amplitude of the continuous wavelet transform (CWT) within plausible cardiac frequencies (30–220 beats per minute)	The frequency corresponding to the maximum amplitude of the CWT within plausible cardiac frequencies
Feature Based Methods		
BW	**AM**	**FM**
Mean signal value between consecutive troughs	Trough amplitude	Time interval between consecutive peaks
Kernel principal component analysis using a radial basis function, with the variance of the Gaussian kernel determined by maximising the difference between the first eigenvalue and sum of the remainder	Peak amplitude	Q and S waves were identified as the minima immediately before and after the R wave
Mean amplitude of troughs and proceeding peaks	Difference between the amplitudes of troughs and proceeding peaks	QRS duration
-	QRS area, defined as the integral of the ECG between Q and S waves after subtraction of a baseline linearly interpolated between Q and S waves	
	RS slopes measured by fitting a straight line to an 8 milliseconds (ms) interval of ECG centered on the time of maximum downslope between R- and S-waves	
	QRS-wave angles measured as the difference between QR and RS slopes	

C. Linkage Concerning HR and BT

A study conducted over 4,493 acute patients collected from the medical admission unit at Sydvestjysk Sygehus, Esbjerg in deriving the relationship exists among HR and BT. The results obtained the study confirms the existence of a strong association among the HR and BT. It is stated that a rise in body temperature is a follow-up indication of increased HR and RR [13].

Theoretical fact agrees that ECG is a single biological sign, and with the help of that other signs can be derived. There is still an open scope for the non-invasive methods to monitor physiological signs of human remotely with less circuitry device.

IV. CONCLUSION

The health care providers believes that only non- invasive real time monitoring gadgets promotes the medical services extended to all citizens in future. With revolutionary techniques like artificial intelligence, big data, cloud computing, machine learning, internet of things and various statistical techniques in this digital era paves the assurance of such ambulatory assistant device. The dependence mapping exists between the physiological measures and methods discussed are utilized in designing a real time monitoring device with reduced sensor and circuitry, works based on acquired single biological signal. For respiration and BP estimation no single method performs well. A novel collection of methods that predicts the respiratory signal and BP well can be investigated further by exploring the technical factors influencing the accuracy through machine learning algorithms.

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