Quantitative assessment of physiological parameters and heart rate variability techniques for analysing Cardiac health

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ABSTRACT
Cardiovascular diseases (CVD) are a set of irregularities of the heart. The number one root cause of death globally is cardiovascular diseases. ECG and heart rate gives the condition of cardiac health. Time domain and frequency domain analysis is done on the ECG signal which can be useful in analysing health condition with the effect of physiological parameters. The stress, angina, cholesterol, blood sugar attributes are taken into consideration. The statistical parameters in time domain which have been considered are the standard deviation of the NN intervals (SADNN) and the root mean square of successive difference intervals which are taken from heart rate signals (RMSSD). The frequency domain parameters which are considered are low frequency (LF), high frequency (HF) and LF/HF ratio which will enable to predict health condition irrespective of age groups. The indexes based on HRV prove a strong predictor of increased all-cause cardiac and/or arrhythmic mortality, particularly in patients at risk after MI or with CHF. Algorithm was implemented in such a way that it will surpass the limitations of existing algorithms. The paper also reveals the role physiological situations, various pathological settings & its role along with HRV indexes for interpretation of subject health.

KEYWORDS: heart rate, SADNN, RMSSD, LF/HF, cardiac arrhythmia.

INTRODUCTION
In recent years, in the field of HRV analysis has found more interest in these time phase and new statistics are found from the physics and have been recommended as complimentary to traditional measures of time and frequency domain [1]. At the same instant, older algorithms are constantly being refined, and advanced methods are being tested in addition to further improve the estimation of required parameters in health and disease [2]. The electrocardiogram of a person gives the total electrical and muscular functions of a human heart and information about cardiac health [3]. The waveform with a peak is usually referred as P-wave [4]. It represents the atrial depolarization that is the requisite time for an electrical impulse generated from the sinoatrial node to proliferate all over the atrial musculature. The QRS complex represents ventricular depolarization and comprises of three waves - the Q-wave, the R-wave and the S-wave. Q wave is present at the beginning of QRS complex [5]. It is the first negative deflection. The first positive deflection is depicted by R-wave, irrespective of the fact that it is surpassed by a Q-wave or not S wave is the next negative aberration which is superseded by the R-wave [6]. Processing of cardiac signal and recognizing the cardiac disorders is challenging task in biomedical signal processing. The state of cardiac heart is generally studied in the shape of ECG waveform. Computer based ECG analysis can provide information regarding various Cardiovascular diseases. According to the statistics, in the year 2015 there are 61.5 million cases of cardiovascular diseases [18]. A challenging effort in medical
industry is to produce effective treatments to patients and to determine the disease accurately.

Subjects and methods:
The database used in this study is acquired from physio-Bank which is available on-line. Also database acquired from exclusively developed hardware and software kit. The source of the ECGs included in the Dataset is a set of over 4000 long-term Halter recordings. Around 60% of these recordings were obtained from inpatients. The groups were chosen to include complex ventricular, junctional, and supraventricular arrhythmias and conduction aberrancies. Tachycardia. By placing the electrodes on the chest, we can get a modified limb lead II (MLII) that is the upper signal in most of the records. In order to restrict analog-to-digital converter (ADC) saturation firstly the analog outputs of the playback unit were filtered and then anti-aliasing is done by utilizing a pass band from 0.1 to 100 Hz relative to real time. The sampling frequency was chosen in such a way that it makes easier the implementations of 60 Hz (mains frequency) digital notch filters in arrhythmia detectors [8]. The digitized ECG signal is processed in MATLAB software. The Time domain and frequency domain analysis is done onto the series of successive R-R interval values.

Techniques:
A Time domain analysis:
Variation in heart rate may be assessed by a number of methods. Perhaps the simplest to perform are the time domain measures. With these techniques either the heart rate at any point in time or the intervals between successive normal complexes are determined [9]. In a continuous ECG record, each QRS complex is detected, and the so-called normal-to-normal (NN) intervals or the instantaneous heart rate is found. The parameters the mean and the variance of R-R interval signal plays an important role and can be utilized for the classification along with the power content in low and high frequency bands [10]. From the original R-R intervals, the standard measures parameters used in this work are:

A 1. The standard deviation of the NN intervals (SDNN):
SDNN is the simplest statistical HRV feature to calculate. NN stands for time interval between consecutive normal sinus heart beats. The standard deviation reflects all the cyclic elements responsible for variability in the period of recording. It can be calculated for 24 hours long-term recordings and for short-term, five minutes recordings SDNN can be calculated for short periods and long periods as a measure of long-term variation [11].

A 2. The root mean square successive difference of intervals (RMSSD):
Root Mean Square of the Successive Differences (RMSSD) is one of a few time-domain tools used to assess heart rate variability, the successive differences being neighbouring RR intervals. Thus, it can be calculated using the expression:

$$RMSSD = \frac{\sqrt{\sum_{i=1}^{N-1}(x_{i+1} - x_i)^2}}{N}$$

Where $x_i$ denotes the length of an R-R interval with index $i$.

B Frequency Domain Analysis:
Frequency domain is concerned with the analysis of mathematical functions or signals with respect to frequency. The two main frequency components are the low frequency (LF) components and the high frequency (HF) components. High frequency component (HF) i.e. spectral component around the respiratory frequency and mainly related to vagal affair, the second one a low frequency component (LF) having power variations related to sympathetic activity [9]. Frequency domain analysis was done by non-parametric based method. We have also evaluated and analyzed the LF/HF ratio. LF/HF: HRV signal is transformed into frequency domain and the ratio of spectral power in lower bound to spectral power in upper bound is to be calculated. The lower bound frequency power is correlated to controlling temperature and cardiovascular mechanism and the upper frequency is related to the cardiac vagal activity.

C Non Linear Method:
There is an increasing interest to analyze HRV using methods other than the standard linear methods. These techniques are termed as nonlinear HRV analysis. The new approach Scale Invariant Structure (SIS) method is based on Detrended Fluctuation Analysis (DFA) [10]. A new approach has been introduced to characterise the variability of the RR series. This approach, known under the different names of Poincare’ plot, Lorenz plot and return map, gives a graphic representation of the behaviour of a dynamic system observed stroboscopically at given, constant time intervals. In the specific case of HRV analysis, the observation is usually performed in the bidimensional space of pairs of consecutive beats (RRi, RRi+1) [11]. Coronary angiography, Stress testing, Electrocardiogram (ECG), CT scan and an MRI scan are the different standards to determine coronary heart
disease [13]. Preventive measures of Coronary heart disease includes no smoking, exercise every day, controlling weight of the body and managing blood cholesterol level, regularly controlling diabetes and high blood pressure levels [14].

The FFT-based period gram can be calculated by using FFT algorithm and then simply squaring the FFT coefficients. In order to calculate the wavelet measures, there is a three-step procedure defined for obtaining the wavelet packet coefficient. [15]

![Fig. 1: Depiction of relation among three domains with HRV](image)

**Implementation:**

The start of the process is by taking the signal of the cardiac patient. The ECG signal of the cardiac patient is extracted providing the necessary information of the signal and the cardiac disorder. Using the process, the geometrical and statistical parameters like time domain and frequency domain parameters are calculated. Twenty-four hour electrocardiographic recordings were performed with a portable two channel tape recorder. The data were sampled digitally (frequency 256 Hz) and transferred to a computer for analysis of Variability. All recordings were first edited automatically followed by careful detailed manual editing. The standard deviation of all normal beat intervals and mean length of the R-R intervals were used for conventional time domain measurements as shown in Fig.2.

In proposed research, pre-processing techniques consists of noise elimination, removing records with missing data, fill in default values and classification of features for decision making at distinct levels.

![Fig. 2: Feasibility of the process implementation](image)

**Table 1:** Attributes for detection and classification purpose. Around same number of patients recording is done for even less than 5 minutes.

The segregation is done on the basis of following attribute.

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Age</td>
<td>Age in Years</td>
</tr>
<tr>
<td>A2</td>
<td>Sex</td>
<td>1=male, 0=female</td>
</tr>
<tr>
<td>A3</td>
<td>Cp</td>
<td>Chest pain type: 1 = typical angina 2 = atypical angina 3 = non-anginal pain 4 = asymptomatic</td>
</tr>
<tr>
<td>A4</td>
<td>Trestbps</td>
<td>Resting blood sugar (in mm Hg on admission)</td>
</tr>
</tbody>
</table>
The main objective is to predict heart disease in this research work by using risk factors like age, sex, chest pain type, exang, old peak, resting blood sugar, cholesterol, resting electrographic results, thalach, slope, fasting blood sugar, number of major vessels colored by fluoroscopy and thal.

**Results:**

Heart rate variability shows significant dissimilarities for both time domain and frequency domain parameters between disorder group (D) and healthy group (H). Time domain and frequency domain indices of heart rate variability are depicted in table-2 and table-3 respectively. In Time domain, group (D) has reduced parameters like SDNN (ms) and RMSSD (ms), compared to the control group (H). Control group have comparatively higher values than disorder group i.e. group D.

Table-3 summarizes the results of frequency domain parameters. In frequency domain analysis in the disorder group, HF power, indicating parasympathetic activity and LF power, specifying mainly sympathetic activity, both were decreased. LF/HF ratio is calculated as shown in the table. The value of LF/HF ratio is significantly higher in group-D than group-H, which indicates dominance of sympathetic activity. Depressed HRV may reflect a decrease in vagal activity directed to the heart. HRV in patients surviving an acute MI reveal a reduction in total and in the individual power of spectral components.

<table>
<thead>
<tr>
<th>Time Domain parameters</th>
<th>(D) Disorder Group</th>
<th>(H) Healthy control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean RR (ms)</td>
<td>790.58</td>
<td>840.44</td>
</tr>
<tr>
<td>SDNN (ms)</td>
<td>34.39 ± 15.85</td>
<td>45.78 ± 9.96</td>
</tr>
<tr>
<td>SDANN</td>
<td>11.65</td>
<td>18.10</td>
</tr>
<tr>
<td>RMSSD (ms)</td>
<td>27.19 ± 17.70</td>
<td>36.18 ± 11.69</td>
</tr>
</tbody>
</table>

The database of male and female is taken into consideration with age group between 40 to 90. The database which is been taken are 6 male subject and 6 female subject and calculated the time domain and frequency domain parameters of all these Subjects as per the process. We have taken the average.

<table>
<thead>
<tr>
<th>Frequency Domain parameters</th>
<th>Disorder Group</th>
<th>Healthy controls Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF power (Hz)</td>
<td>1.12-6.527</td>
<td>0.2080-0.645</td>
</tr>
<tr>
<td>LF/HF Ratio</td>
<td>10.81 ± 4.23</td>
<td>1.39 ± 0.78</td>
</tr>
</tbody>
</table>

values of all these subjects and separated the male and female values. The calculated parameters are SDNN, RMSSD and LF/HF as shown in the figure Fig.3 and Fig.4 shows subjects under broad category as per attributes.

**Fig. 3:** Cardiac disorder detection with attributes A1 to A5

A subgroup analysis was performed for subjects without known or suspected heart disease at the time of entry by excluding subjects with angina pectoris, previous myocardial infarction, heart failure, impaired
functional class and subjects taking any cardiac medication.

Fig. 4: Health Status base on Attributes A6 to A9

In the figure above, it can be seen that the values of time domain parameters like SDNN and RMSSD is comparatively higher in male than female subjects. Also the ratio of LF/HF is higher in male than compared to female which indicates the dominance of sympathetic activity more in male. Even if heart rate value increases, LF/HF ratio was largely unaffected by either acute myocardial ischemia, exercise. Thus, the LF component of HRV does provide an index of cardiac sympathetic drive but also reflects a complex sympathetic, parasympathetic, and other unidentified factors accounting for the largest portion of the variability in this frequency range.

In the next section, the bifurcation of age wise comparison is shown. In the first group age below 60 are taken and in the second group age above 60 are taken which are the senior citizens. The total subject taken is 10, out of which 5 are below 60 and rest 5 are above 60 i.e. senior citizen.

Fig. 5: Age-wise Comparison.

The value of RMSSD is almost alike with a very less variation as seen in the figure. The LF/HF ratio is also calculated. The ratio value is higher in patients with age less than 60 as compared to senior citizens.

Table 4: Correlation between cardiac disorders and symptoms

<table>
<thead>
<tr>
<th>Cardiac Disorder</th>
<th>Bradycardia</th>
<th>Normal HRT</th>
<th>Tachycardia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading</td>
<td>Below 50 bpm</td>
<td>60-90 bpm</td>
<td>Over 100 bpm</td>
</tr>
<tr>
<td>Symptoms</td>
<td>Functional/anatomical heart problem (Heart failure/Heart arrest) Drug side effect</td>
<td>-</td>
<td>Stress and anxiety Anaemia</td>
</tr>
</tbody>
</table>

The above figure gives indications that higher power in LF and HF represents greater flexibility and a very robust nervous system. Sedentary people have numbers in the low 100’s (90-300) or even lower LF/HF, fit and active people are around 850 – 1650 and so on as fitness and health improve on this basis.

A higher number of LF/HF ratio indicates increased sympathetic activity or reduced parasympathetic activity. Also sometimes, this ratio is an indicator of SNS activity. Tracking LF and HF together can really illustrate the balance in system. Even if two are to to be relatively close as shown in fig.6. When ratios are not close to each other, it may indicate that the body is in deeply rested state with much parasympathetic nervous
system activation (HF is high). In a stressed state with too much sympathetic nervous system activation (LF is high) with a very less difference. It has reflected in patients with age less than 60, indicating the supremacy of sympathetic activity more.

Fig. 6: LF Vs HF for analysis of subject health

Fig. 7: Age wise comparison.

The presence of an alteration in neural control is also reflected in a blunting of day-night variations of RR interval as shown in Fig. 7. It does have variations which will introduce possible non-linear effects of varying cardiac sympathetic and cardiac parasympathetic nerve activity on LF/HF, MSE parameters.

Conclusion:

In the present study, the data so evaluated in term of the various parameters of HRV. The relation to the presence of other physiological parameters along with HRV indices has also being carried out.

Time domain and frequency domain analysis of the RR interval variability of cardiac disorder and normal subjects shows that there is significant difference in these measures for disorder patients with respect to normal subjects. HRV parameter like Low Frequency (LF) components was higher in males, which reflect sympathetic dominance in males. High Frequency (HF) component of HRV was significantly higher in females, which indicates parasympathetic dominance in females. The study gives good results of the parameters irrespective of the age and gender of the patient having cardiac disorder. So it is expected that these measures allow early detection and treatment/subsequent management of patients and thus can avoid complications.

The study also reveals individual parameters or indexes will extract information without physiological interventions which is to be investigated further for more accurate interpretations. The study also emphasized on the need to collect samples of subject/s in different time lag so as to arrive at correct prediction.

REFERENCES

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