Identification of atrial fibrillation using electrocardiographic RR-interval difference

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Abstract. Automated detection of atrial fibrillation (AF) is an interesting topic. It is an account of very dangerous, not only as a trigger of embolic stroke, but it’s also related to some else chronical disease. In this study, we analyse the presence of AF by determining irregularities of RR-interval.

We utilize the interval comparison to measure the degree of irregularities of RR-interval in a defined segment. The series of RR-interval is segmented with the length of 10 of them. In this study, we use interval comparison for the method. We were comparing all of the intervals there each other. Then we put the threshold to define the low difference and high difference (δ). A segment is define d as AF or Normal Sinus by the number of high δ, so we put the tolerance (β) of high δ there. We have used this method to test the 23 patients data from MIT-BIH. Using the approach and the clinical data we find accuracy, sensitivity, and specificity of 84.98%, 91.99%, and 77.85% respectively.

1. Introduction

Atrial fibrillation (AF) is an abnormality of atrial mechanical activity caused by very rapid and irregular electrical impulses that occur during atrial depolarization process [1][2]. Atrial depolarization is illustrated by P wave [2]. In the event of AF, P wave is not be visible because it replaced by the high frequency of fibrillation. [3]

AF could affect the increase in mortality and morbidity from stroke, heart failure, injury of neurology, and the greater disability. Patients with AF had five times higher stroke risk and three times higher risk of heart failure than patients without AF [4].

The most frightening complications of AF is the incidence of embolic stroke. The average annual risk is about 4.5 % in individuals with AF [1]. Atrial arrhythmias have varied proposed pathophysiology mechanism, they are one or more rapidly discharging foci, ordered reentry of short cycle length and random re-entry [1][10]. These processes lead to mechanical dysfunction with resultant thrombus formation in the complex [10].

The estimates prevalence of AF in the USA is 5.2 million, in the European is 8.8 million, in the Middle East is 4.9 million, and in the Asia is 4.2 million of the adult population [1]. In the Asian population, the described factors were: age above 80 years, history of heart disease, diminished glomerular filtration rate, and hypercholesterolemia. [11]. AF is also affects to 0.4% of the general population [8][9].

From the observational study of MONICA (Multinational Monitoring of Trend and Determinant In Cardiovascular Disease), it was found that in the urban population in Jakarta, the incidence of FA was
0.2% with the male and female ratio of 3 : 2. It also due to the significant increase of the percentage of elderly population in Indonesia by 7.74% (from 2000-2005) to 28.68% (WHO estimate of 2045-2050), the incidence of FA would also increase significantly [7].

International guidelines have classified AF as: (1) the detected AF for the first time (symptomatic or not, self-limited, or of unknown duration, or when the presence of previous episodes is unknown, being paroxysmal or persistent); (2) paroxysmal is characterized by recurrent episodes and spontaneous reversion; (3) persistent or lasting more than seven days and needing chemical or electrical cardioversion to re-establish the sinus rhythm; And (4) permanent or lasting more than one year, and refractory to cardioversion. [12]

Based on this classification, it needs continuously ECG recording to make a classification. However, based on the accuracy of some studies, at least AF monitoring performed over 72 hours [13]. This process could make it difficult for patients to be in bed for more than three days. Moreover, the physician has a big trouble to analyzing that much data. To help the physician in this job, a system of artificial intelligence who can read and diagnose whether a normal heartbeat or atrial fibrillation is required.

If we are referring to the initial definition of atrial fibrillation, irregularity of excitation, and atrial recovery, the basic of AF detection is read as to the loss of P waves as they are enclosed by Atrial Fibrillation. But in the ECG lead, there are at least two types of fibrillation that describe the characteristics of atrial fibrillation. First, coarse fibrillation. It is appearance of high-amplitude fibrillation waves, more than 1 mm. It is often seen in heart disease with large atria, the heart valve disease. Then fine fibrillation, it occurs in coronary heart disease [2][6]. Fine fibrillation is illustrated by the loss of P waves and the appearance of low-amplitude fibrillation waves, less than 1 mm. Sometimes Fibrillation waves do not appear significantly, so diagnostic enforcement is based on irregular QRS responses or arrhythmias [2][5]. In line with this statement, many researchers from biomedical use RR interval irregularity as a key feature.

There have been many investigations of AF automation detection using the degree of RR-irregularity interval. The used methods are CoSEN [15][16], RMSS, Coefficient Variance, Median absolute deviation [7], Detrended Fluctuation Analysis [16], Local Dynamic Score[16] and so on. In this study, we introduce a way to detect the irregularity of the RR interval by the interval comparison method. We were comparing all of RR-interval in the segment each other. The difference of the comparison yields a difference coefficient which can be used to classify the normality of a segment.

2. Material and Method

2.1. Data
In this study, we use data from MIT-BIH published by physionet [17]. The data are R peaks detected from 24 hours recording of 23 patients. From the presence of the R peaks, we detect the length of the overall RR intervals of the data. From the RR intervals, we get this research started.

2.2. Pre-Process
From the data, we get about millions of RR intervals. The series of RR-intervals is segmented with the length of 10 of them. This length is proportional to the 8-second recording, assuming a general heart rate period. This segmentation is almost identical to the research by Lake and Moorman in 2011[15]. They operate the method of the coefficient of sample entropy for short segments, along 12 intervals. Each beat has a basic description of normal or AF. In this encrypted research we attach it to each segment. Each segment has one identity description, its normal or AF. This identity is determined by considering the AF frequency of the base description on all data in that segment.

2.3. Process
In this study, we use the method we call the interval comparison operation. In the case of AF, the length of an interval is not the same as the length of the other interval.
In this study we have ten intervals in each segment. If in that segment there is a length of an interval is different from the length of nine other intervals, then we assume that the segment is AF.

The value of the difference between the first interval ($I_1$) and second interval ($I_2$) is not equal to the value of the difference between the first interval ($I_1$) and the 3rd interval ($I_3$). As described by equations 3.1 and figure 1. Furthermore, the value of the difference between the intervals we call the difference ($\delta$).

$$\delta_{12} = |I_1 - I_2|$$

$$\delta_{12} \neq \delta_{13} \neq \cdots \neq \delta_{19} \tag{2.1}$$

The next is also true:

$$|I_1 - I_2| \neq |I_2 - I_3| \tag{2.2}$$

The first interval ($I_1$) have nine $\delta$ when operated with 9 other intervals. The second interval is also, when compared to 9 other intervals it would have 9 $\delta$. Since the second interval ($I_2$) has already been operated with interval 1-on operation $I_1$, then $I_2$ only needs to be operated with 8 intervals thereafter. Based on this description we can conclude that $I_1$ has 9 $\delta$, $I_2$ has 8 $\delta$, $I_3$ has 7 $\delta$, etc. So, from all operations, overall we get as much as 45 $\delta$ in each segment.

Back to the problem that one of the AF indications is the presence of arrhythmias or irregularities of RR-Interval on ECG recordings. Easily we can say that if a segment is a normal segment, then each of the 45 $\delta$ has a value of 0. That is, there is no difference in length at all between an interval with nine other intervals. But in practice, the difference of the intervals in the normal segment is not absolutely zero. Each interval still has differences with each other with small values. We assume that if a segment is called an arrhythmia when the number of difference is many or large. The number of difference can be said to be large or small when we have placed a threshold between the two.

In this study we tried to put the threshold values several times, i.e., 11, 13, 15, and so on up to 31. We find that value is from manual observation of some segment of AF and some segment of normal. Furthermore, we call the threshold ($\sigma$) for them. And remember that we call $\delta$ for the value of different.

Furthermore, the meaning of threshold selection is if the difference between intervals ($\delta$) is smaller than $\sigma$ then the $\delta$ is ignored, and the $\delta$ of interval is considered as a low $\delta$. Conversely if the value of $\delta$ more than $\sigma$, then we assume that the $\delta$ is a high $\delta$. To determine a normal or fibrillated segment then

| $I_1$ = first interval |
| $I_2$ = second interval |
| $I_n$ = nth interval |
| $\sigma$ = Threshold |
| $\beta$ = Tolerance |

Input $I_1, I_2, I_3, \ldots, I_{10}$.

$$\delta_{n,n \neq n} = |I_n - I_{n \neq n}|$$

$high \delta = find (diff_{n,n \neq n} > \sigma)$

If number of $\delta > \sigma$

segment = AF

else segment = normal

Figure 1. Pseudocode of algorithm intervals comparison.
we calculate the number of high $\delta$. If there is more higher $\delta$ than the tolerance $\beta$ then we consider the segment is AF.

In this research, we put tolerance four times. It is 0 of high $\delta$, 3 of high $\delta$, 6 of high $\delta$, and 10 of high $\delta$.

3. Result
We tested this method on 23 patients. The smallest interval difference we get is 0, the meaning is that the interval with the other has the same length. We not only compare an interval with the closest interval, but also compare it with some intervals thereafter. Each interval in a segment relates to each other, to form a $\delta$ value. The method to calculate this $\delta$ is results more fluctuation of data. So, it gives us more opportunity to try the advanced method.

In this study, AF is defined as a state when the number of high $\delta$ in the segment is more than the number of tolerances $\beta$. In the process of threshold $\sigma$ modification and tolerance $\beta$ modification we get a variety of data as described in table 1.

Each modification of the maximum tolerance of the threshold value is also subject to change, as described in graphs in figure 2.

Based on these results, in this study, we determined the best threshold $\sigma$ is 23, and the best tolerance $\beta$ is 3. The results we get in the process are accuracy, sensitivity, and specificity of 84.98%, 91.99%, and 77.85%, respectively.

| $\sigma$ | $\beta=0$ | $\beta=3$ | $\beta=6$ | $\beta=10$ |
|---|---|---|---|---|
| 11 | 78.43 | 79.44 | 80.50 | 83.13 |
| 13 | 80.70 | 81.47 | 82.26 | 84.18 |
| 15 | 82.09 | 82.70 | 84.32 | 84.77 |
| 17 | 83.05 | 83.54 | 84.45 | 84.95 |
| 19 | 83.67 | 84.07 | 84.44 | 84.94 |
| 21 | 84.03 | 84.33 | 84.36 | 84.72 |
| 23 | 84.25 | 84.98 | 84.16 | 84.41 |
| 25 | 84.38 | 84.50 | 83.97 | 84.00 |
| 27 | 84.41 | 84.42 | 83.32 | 83.53 |
| 29 | 84.38 | 84.30 | 83.92 | 83.00 |
| 31 | 84.34 | 84.17 | 83.59 | 82.37 |
4. Discussion
After all of the data is segmented, then we operate the interval comparison method to each segment. Since each segment produces 45 δ, then, overall we have about 47.456.640 δ. The smallest δ of them is 0, and the biggest one is about 1638.

To determine a δ including low or high δ we place a threshold. In this experiment, we modified several times of thresholds ranging from 15 to 31. Then to determine a segment to be AF or normal, in each trial threshold, we test it on some variations of high δ tolerance β. In this experiment, at least we tried four times the number of tolerance, 0, 3, 6, and 10.

For the tolerance number 0, when the threshold is rise, the accuracy rise as well until the threshold reaches 27. After that, if the value of threshold is increased, then the accuracy is down. Such trends is also apply to tolerance numbers 3, 6, and 10. The accuracy is gets higher as the threshold rises, then stops at a certain point, then accuracy falls back. The stop point, or the point when we get the best accuracy we call the maximum threshold point. It is described by Figure 2.

For the tolerance number 0, the best threshold is 27. For the tolerance number 3, the best threshold is 23. For the tolerance number 6, the best threshold is 17. For the tolerance number 10, the best threshold is 17.

Based on these data, after the 3 (6 or 10) tolerance number, the trend of accuracy is getting down. This trend is due to the high tolerance, precisely some segments that actually AF cannot be recognized by the program. This means the program considers the segment as normal. So, the answer of the program is wrong. Hence, the accuracy is low.

The data presented by MIT-BIH is not only consisting of Normal Sinus and AF, but there is also Fluter atrium (AFL) and AV Junction (J) on the recording of some patients. Because AF and normal use binary classification, we have to make a decision whether AFL and J are included in the normal or not.
Knight (1999) [14] revealed that medically the Flutter atrium has regular RR intervals. Based on the statement, the identity of AFL segment should be zero, of course, it’s because the value of the $\delta$ must be low. So, with this method, the AFL segment should be detected as a normal segment. However, our results show that the AFL segment belongs to the fibrillated segment.

It is the same as what Lake’s done with his crew (2011) [15]. That they were evaluated this measure with a clinician's eye. Especially regarding the atrial flutter (AFL) ECG recordings. This rhythm of RR intervals is very regular when in a stable conduction, but is clinically treated much like AF. Thus, they were categorized AFL as AF, even though its regular. This regularity is make an entropy of RR interval time series are low. It's very different from irregular RR interval. It has high-entropy AF. Throughout, they were analyzed AFL and AF together. Although the AFL algorithm would improve, if they excluded the AFL.

5. Conclusion
We have conducted a study of atrial fibrillation detection using the difference of electrocardiographic RR-intervals. The difference is obtained by comparing all intervals in a segment each other. We varied the threshold of the difference and tolerance. Using the approach and the clinical data we find accuracy, sensitivity, and specificity of 84.98%, 91.99%, and 77.85%, respectively. Thus, it implies that the RR interval difference is quite effective to detect the atrial fibrillation.

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