Help System for Medical Diagnosis of the Electrocardiogram

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Abstract — **This presentation is part of a work that aims to create an interactive learning medical system of ECG events and pathologies diagnose. The system can be seen as an interactive game in wish the user will practice with ECG signal of several pathologies For this purpose an algorithm was developed that detects the events of the ECG in MATLAB. This paper is focus on the discussion of the algorithm, connections between the ECG and the heart physiology listing several pathologies and their respective ECG patterns. A preparatory smoothing of the signal is performed. The algorithm is now only applicable to the normal ECG. It is based in correlation of events within a period of the ECG, and finds the P wave and T wave searching the peaks under a confined region of the smoothed signal.**

Keywords- electrocardiogram, ECG event, Cardiac pathologies.

I. INTRODUCTION

The tool developed is a part of interactive learning software used for ECG events identification and their association to the respective pathologies. In this paper is presented the algorithm techniques used to detect and mark the P, QRS, and T events of a normal ECG.

During this paper a study of the cardiac diseases and the signal from the electrocardiogram will be done.

It is possible connect the electrocardiogram exam to heart diseases because any changes in the morphology of the heart will modify the propagation of waves of repolarisation/depolarization. Each heart disease makes changes standard in the signal of electrocardiogram. So, the electrocardiogram signal will be changed or some electrocardiogram events will be missed. This project can concomitantly have the scope of creating a tool of algorithms capable to automatically identify the several events of the ECG, detect the missed events and based on that information an intelligent system should suggest the disease to the medical doctor. The final performance of the algorithms set would be important to decide the usability as a serious game or a medical diagnose system.

In this paper the automatic events detection of a healthy ECG is presented.

The techniques used where for detect the events of a normal ECG can be substantially modified and/or adapted when used for a specific pathology.

II. THE HEART

The heart is the most important organs of the human body. This organ is a central pump and has the mission of create blood pressure that provides oxygen and nutrients to all cells of the body [1] [2].

The heart is a muscular organ with the size of a fist and comports four chambers: right atrium (or auricle), left atrium, right ventricle and left ventricle. The two chambers upper and lower are called auricles and ventricles respectively. The wall that separates the heart into a right and left side are called septum [2]. The two sides of the heart are like a twin pumps. They are combined in a single organ but placed in series in the vascular system, where their connections have the purpose of separating the arterial from venous blood. The arterial blood is rich in oxygen and the venous blood in carbon dioxide.

To direct the flow of blood and prevent its backward movement the heart has four valves. The valves between the auricles and the ventricles are atrioventricular valves. The atrioventricular valve on the left side is called bicuspid or mitral and the atrioventricular valve on the right side is called tricuspid. The other two valves are the semilunar valves and they are between the ventricles and their attached vessels [2].

A. Cardiac Cycle

The human heart beats ceaselessly about 60 times a minute until the end of his life.

The cardiac cycle begins with the simultaneous contraction of the auricles. Then, same happens with ventricles. Finally, the auricles and the ventricles relax. The phase of contraction the chambers is called systole and the phase of relax is called diastole. Although, when the auricles are in diastole, the ventricles are in systole and vice versa [2].

When the auricles are in systole, the atrioventricular valves are open and the semilunar valves are open when the ventricles are in systole.

B. *Control of Heartbeat*

The intrinsic conduction system is responsible to the rhythmical contraction of the heart. There is a type of a cardiac muscle located in two regions of the heart. This muscle has muscular and nervous characteristics and is called nodal tissue. The two nodes in the heart are the sinoatrial node (or SA node) and the atrioventricular node (or AV node). The SA node is located in the upper dorsal wall of the right auricle and the AV node is located in the base of the right auricle very near the septum [1] [2].

The heart beat initiate with an exciting impulse sent by the sinoatrial node. This impulse causes the contraction the auricles. The impulse reaches the atrioventricular node and this cause a slight delay allowing the auricles finish the contraction. The next step is the contraction the ventricles. The impulse is now sent to the atrioventricular bundle (or AV bundle) and then immediately arrives to the numerous and smaller Purkinje fibers.

As explained, the sinoatrial node is very important because his responsible to keep the heartbeat regular. If the SA node fails the heart still beats by the impulses generated by the AV node. However, the rhythm is slower [2].

III. THE ELECTROCARDIOGRAM

The electrical changes that occur during a cardiac cycle can be recorded by an electrocardiogram. The electrical impulse that travels through the heart is conducted by the ions present in the body fluids. These ions contained in the body fluids allow electrical changes in the cardiac cycle that can be detected on the skin's surface.

To take a electrocardiogram exam it is necessary to connect the electrodes placed on the skin to the electrocardiograph that detects the electrical changes in the heart.

When the sinoatrial node sends an impulse the atrial fibers generate an electrical change that is called the P wave. This wave provides information that the auricle is about to contract. When the ventricles are about to contract, the ECG produces the QRS complex [3]. Finally, the relaxation of the ventricles occurs and produces the T wave, as depicted in Fig. 1.

In the electrocardiogram exam various types of anomalies can be detected. Next section discuss several patologies in the ECG.

IV. DIAGNOSIS OF DISEASES BY ECG

By examining the electrocardiogram various types of arrhythmias can be diagnosed. Arrhythmias are caused by altering the formation of electrical stimulation, or of mixed driving. So with the electrocardiogram, we can diagnose: arrhythmias by conduction disturbances, fast arrhythmias by increased arousal and extrasystole [4].

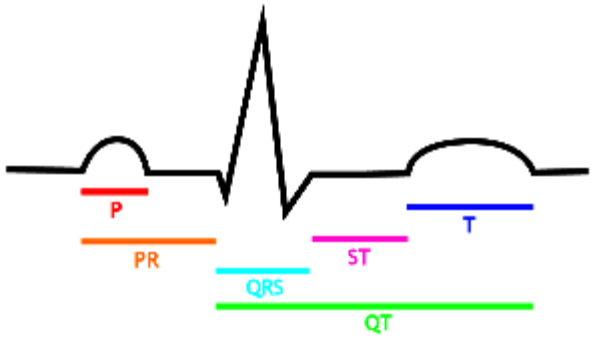

Figure 1- Events of the electrocardiogram.

A. *Arrhythmias by conduction disturbances*

As has been said earlier, the sinus beats about 70 times per minute, with a variation between 60 and 100 beats per minute (and some doctors consider between 50 and 90).

1) *Sinus Bradycardia*

The sinus bradycardia occurs in the sinoatrial node and is characterized by frequencies below 60 beats per minute. The effect on the electrocardiogram is a greater distance between beats, as seen in Fig.2 [5].

2) *Sinus Tachycardia*

The arrhythmia Sinus tachycardia is the opposite of Sinus bradycardia, in other words, heart rate was normal but has a frequency of 100 beats per minute (there are authors who consider 90). As a consequence we will have an ECG in the shortest distance between beats as in Fig. 3 [4].

3) *Respiratory Sinus Arrhythmia*

The Sinus Arrhythmia is characterized by a speed variation that occurs in the heart rate, and has moments that are slow and others it is fast. Thus, the Respiratory Sinus Arrhythmia is to accelerate the heart during inspiration (between 80 and 90 beats per minute) and the heart rate slows during expiration (50/60 beats per minute). Therefore, the ECG signal distances vary between beats as in Fig. 4 [3].

4) *Sinus Node Disease*

In sinus node disease, this node loses its rhythm frequencies causing too slow and/or fast or even breaks due to crashes. We can also have bradycardia alternating with tachycardia, this junction is called a Brady-tacky syndrome.

Thus, the ECG signal will be slow, and may contain pauses, fast forward periods as in Fig. 5 [3].

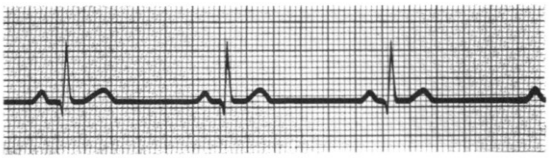

Figure 2 - ECG of a sinus bradycardia [5].

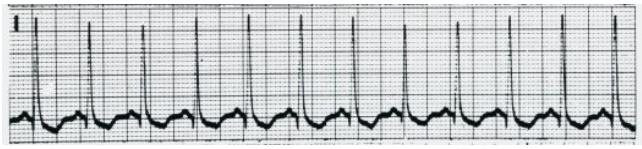

Figure 3 - ECG of a sinus tachycardia [4].

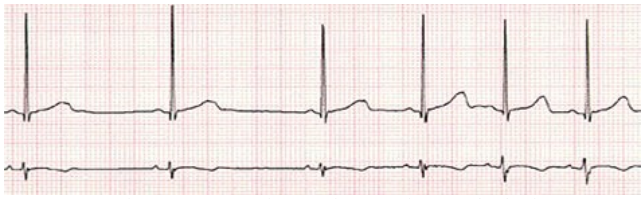

Figure 4 - ECG of a Respiratory Sinus Arrhythmia.

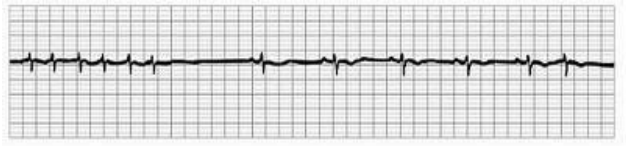

Figure 5 - ECG of a Sinus Node Disease.

5) Atrial Tachycardia

The atrial tachycardia arrhythmia occurs when a focus within the atrium gives the sign or re-enters the local circuit. The tachycardia is caused by rapid firing. This arrhythmia is characterized by a deformation of the P wave, there is usually an increase in heart rate that begins and ends quickly, this may take a few minutes or hours. One example is depicted in Fig. 6 [5].

From the perspective of the ECG signal all of these type of pathologies can be detected by the change of beat rate and not by the change of its shape.

B. Arrhythmias increased by fast excitation

The increased excitability of the sinus node, atrial myocardium or the ventricular muscle fibers can be caused by stimuli from the brain such as excitement, love, hate or stress, the response to drugs in circulation (nicotine, cocaine, caffeine, etc.) or local pathological process (ischemia, overload, inflammation or infiltration) [3].

1) Paroxysmal Supraventricular Tachycardia

This pathology is an increase in heart rate (140 to 180 beats / minute) in a sudden manner, the fastest pace due to an irritative focus headset.

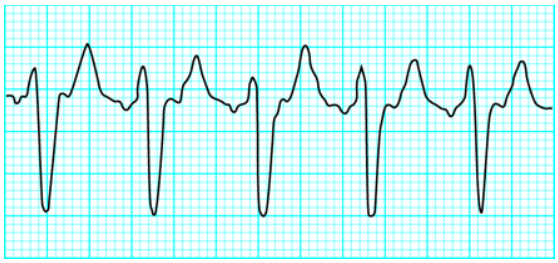

Figure 6 - ECG of a Atrial Tachycardia [5].

One of the reasons for this type of tachycardia is the Wolf Parkinson White Syndrome (WPW), so there is a small congenital muscular bundle which makes the connection between the atrium and ventricle. Thus, electrical stimulation can be transmitted to the ventricles, and these become active soon - pre-excitation.

For the reason stated above, the ECG with WPW syndrome, the QRS complex is narrower than in normal as depicted in Fig. 7 [3].

2) Atrial Fibrillation

The Atrial Fibrillation is a chronic arrhythmia and has an incidence proportional to age (80 years old 10% of the population has Atrial Fibrillation).

There are multiple foci in the atria of excitement, the function of selectivity of these outbreaks, which are transmitted to the ventricles, is the responsibility of the Node atrioventricular (AV).

In atrial fibrillation, the AV node filters out unevenly, causing the heart rate varies between 50 and 200 beats per min, approximately.

In the ECG of atrial fibrillation, P waves are not present, there are small waves that distort the isoelectric line, the QRS complex is narrow and RR intervals are variable as in Fig. 8 [3].

3) Auricular Flutter

Atrial flutter occurs in a circular motion from electrical stimulation of the atria exceeding 300 beats per minute. When it reaches the AV node reaches the ventricles in four, three or two times.

This regularity affect patients as if they are subjected to stress, the frequency increases from 75 to 100 and then to 150 beats per minute, causing them to have shortness of breath and tiredness.

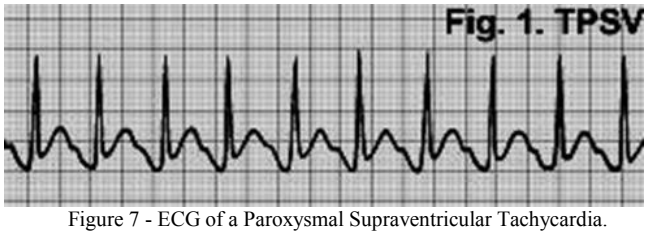

Figure 7 - ECG of a Paroxysmal Supraventricular Tachycardia.

Atrial flutter presents an ECG without P waves, each wave has a similar "sawtooth" denoted by F waves and its frequency is 250 to 350 beats per minute as in Fig. 9 [4].

4) Ventricular Extrasystole

The ventricular premature complex is caused by one or more irritative foci in the ventricular myocardium. Patients feel an empty first, this time the ventricle is contracted ahead of time, little blood being pumped by them. Then there is the filling of the ventricle that leads to a stronger pulse wave. At this stage, patients experience a much stronger beat.

Regarding the ECG, this condition is characterized by a QRS complex wider, premature and abnormal, is not preceded by P wave headset. Then we have a break (due to the filling of the ventricles) to the following P wave. Thereafter the rate becomes normal sinus as depicted in Fig. 10 [3].

5) Ventricular Tachycardia

Ventricular tachycardia usually occurs in people with heart muscle disease. In this arrhythmia, sinoatrial node loses control of his mission as the heartbeat signal and there is a new area of signaling in the ventricles. However, the waves of depolarization and repolarization not run through the heart muscle usually as a result the heart does not have the normal beat.

In ventricular tachycardia 3 or more consecutive ventricular extrasystole (VES) beats occur with a frequency greater than 120 beats per minute. The VES beats are characterized by a change of heart and the following impulses do not follow the normal route. Therefore, there is a change in duration of the QRS complex wave as it is not preceded by P wave, as depicted in Fig. 11 [5].

6) Ventricular Fibrillation

Ventricular fibrillation occurs when multiple foci in the ventricles fire electrical impulses rapidly and with no rhythm. Ventricular fibrillation corresponds to very fast heartbeats, that can reach 300 beats per minute, and a reduced volume is pumped, because the ventricle cannot contract, just shakes. The ECG of this disease is a cluttered layout and lack of QRS complex as in Fig. 12 [5].

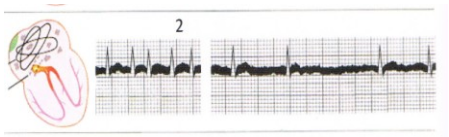

Figure 8 - ECG of a Atrial Fibrillation [4].

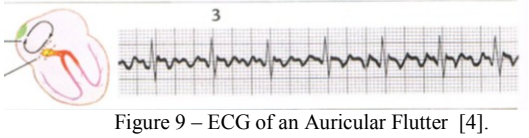

Figure 9 – ECG of an Auricular Flutter [4].

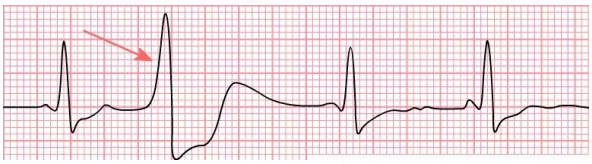

Figure 10 - ECG of a Ventricular Extrasystole [4].

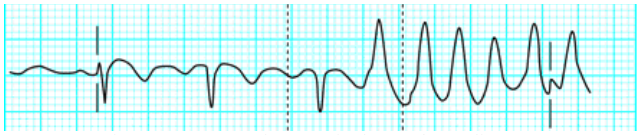

Figure 11 - ECG of a Ventricular Tachycardia.

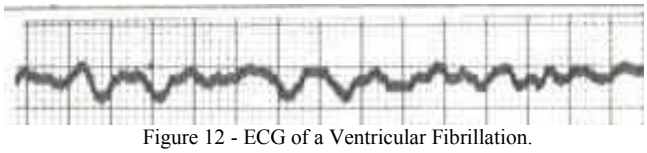

Figure 12 - ECG of a Ventricular Fibrillation.

V. Automatic Detection of Electrocardiogram Events

To implement a system that automatically suggest cardiac diseases by the use of electrocardiogram exam its necessary identify the normal electrocardiogram events fast and then the anomalous ECG. The algorithms were developed under the Matlab program. The electrical signal was downloaded from the database *PhysioBank – physiologic signal archives for biomedical research* and the signal that will be used is *sel100m.mat* [6]. The signal was recorded with a sampling frequency of 200 Hz. Next section present the developped algoritmh to determine the events in an normal ECG.

A. Signal Preprocessing

The electrical signals are vectors, where for each index has a certain value. The signal extracted from the database has duration of 30 minutes, but we used only one section of it with 1500 samples. The used section is present in Fig. 13. After loading the signal, we obtained the section as follows:

```
load('sel100m.mat')
y=val(1,1:1500);
```

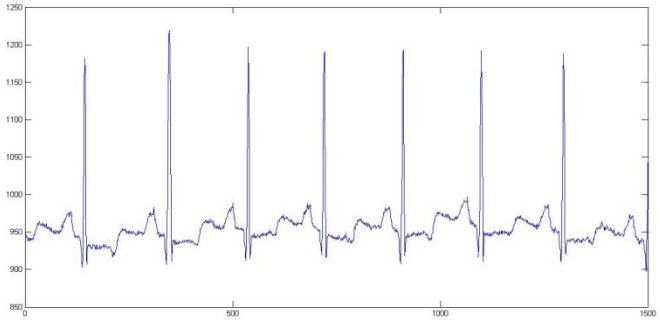

Figure 13- Section of the signal sel100m.mat.

The electrocardiogram signal extracted the surface skin's by the ECG have noise. The noise in the signal is originated in the functioning of others organs and makes it harder to identify the electrocardiogram events. So, first at all we need to smooth the signal removing some high frequency disturbances. For this, we used the moving average filter. In order to remove the very low frequencies noise, some possible offset or DC component and some eventual tendency, a detrend filter was used.

The moving average filter was implemented for the realization of this project. This filter consists in to recalculate the value of an experimental measurement using the average of points ahead and behind that measure. It's designated as a window length, N, the number of points used. In this algorithm is chosen by the user.

In implementing this moving average was necessary to determine the length of the section used (L) by the command *length* and the length N, which half M is rounded to the units using the command floor (rounds toward zero).

The moving average filter Matlab code is presented in following lines:

```
L=length(s);
M=floor(N/2);
for i=1:M,
    m(i)=mean(s(1:i));
end
for i=1+M:L-M-1
    m(i)=mean(s(i-M:i+M));
end
for i=L-M:L,
    m(i)=mean(s(i-M:L));
end
```

The detrend filter consists to remove a linear trend of the vector using the Fourier transform [7].

In our signal we start by smoothing it with a moving average filter using length window N=10 with the result presented in Fig. 14 and then again the same filter but with length N=14 with results present in Fig. 15. So, first we smooth the signal and then remove linear trend using the *detrend* function of Matlab. The final result is presented in Fig. 16.

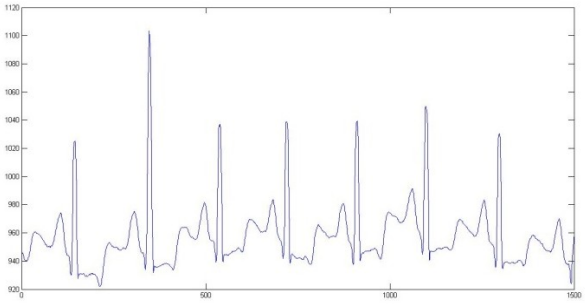

Figure 14 - Signal after applying the moving average filter with N=10.

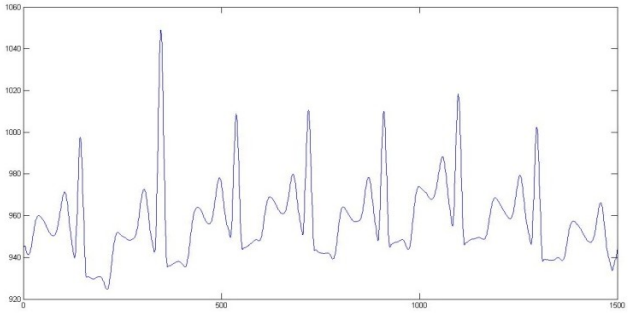

Figure 15 - Signal after applying the moving average filter with N=14.

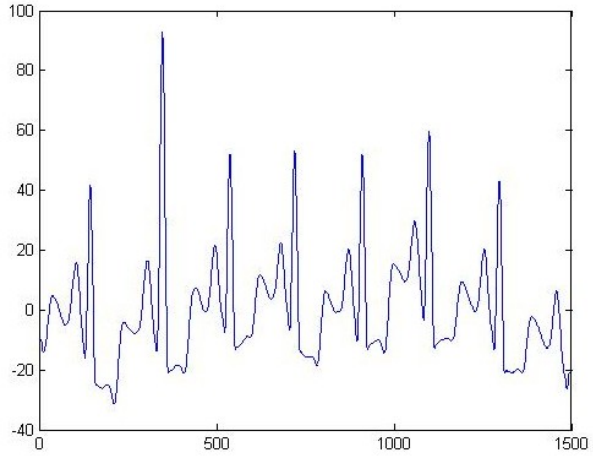

Figure 16 – Clean signal.

Once the signal is smoothed and clean the algorithm to automatically determine the events can now be performed.

B. Automatic Determination of Periods

The duration of cardiac cycle isn't always the same, which makes the period an unknown variable. So, the next step it's to define the duration of the cardiac cycle, in others words, define the period variable.

To identify the duration of the cardiac cycle we used the correlation coefficient. The correlation coefficient is the measure of a relationship between two variables, and this coefficient indicates the direction and strength between them [8].

So, a vector was created containing the searched event that served as a comparison with several segment of same length of the signal. When the correlation of the signal with this vector is about one, it means they are very identical, in other words, we find the event we were looking for.

The event, which was used for automatic detection of periods, was the vector corresponding to the QRS complex. We start by finding the maximum value and the position at which this vector occur. Then it took place a normalization of the amplitude. For points between the start signal and end signal subtracted from the vector length less one, comparison was carried out followed by the normalization of the amplitude. Finally, we calculated the correlation:

```
[u]=length(s);
v_qrs=s(324:336);
[p,ip]=max(v_qrs);
v=v_qrs/p;
L3=length(v_qrs);
for i=1:u-L3-1
   v2=s(i:i+L3-1);
   [p2,ip]=max(v2);
   v2=v2/p2;
  x=corrcoef(v',v2');
end
```

The result of correlation is presented in matrix, being shown as follows:

$$\begin{bmatrix} Correlation\ value\ of\ v'\ by\ v' & Correlation\ value\ of\ v'by\ v2 \\ Correlation\ value\ of\ v2\ by\ v' & Correlation\ value\ of\ v2\ by\ v2 \end{bmatrix}$$

Therefore, for the correlation we have to get the position of (1,2) or (2,1) because these values are equal. In addition, we must increase half the length of the vector comparison to get synchronized. Therefore:

```
xc(i+6)=x(1,2);
```

Fig. 17 shows the signal and below the graph of the correlation. In this graph we can see that the values are between -1 and 1. We also found that when we are at the beginning of the QRS complex (Q point), the correlation is equal to 1, but with the increase of half the length of the vector of comparison gives the QRS complex. This operation is very sensitive, it can be seen in the graph several other points with correlation almost one, but only the values above 0.98 was considered as a candidate.

The aim is to record in a vector the values of the indices in which there is a QRS complex.

As in many areas of the signals, the correlation is too high and other situations may not even be equal to 1, the calculation of periods made itself a condition for the recording of values: the program only records the value of the correlation exceeds 0.98 (this value was obtained experimentally through the analysis of correlation graphs). Finally, we made the calculation of the period of the first cycle.

```
[l]=length(xc);
while i<l
     i=i+1;
     if xc(i)>0.98,
         pico_qrs(j)=i;
         j=j+1;
     end

 end
P=pico_qrs(2)-pico_qrs(1)
```

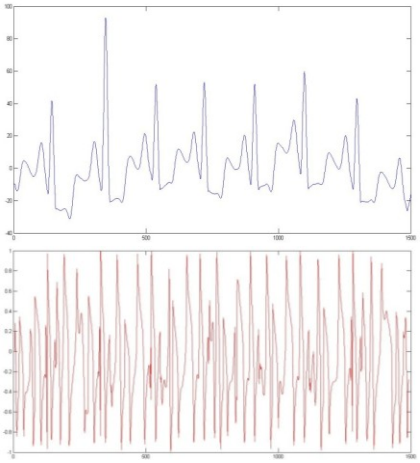

Figure 17 – Above the ECG and bellow its correlation with the QRS complex.

To get the period P in seconds we just need to multiply the P value by the sampling frequency (200 Hz).

This method is very sensitive to the size of the QRS vector used for comparison, because if it is small will often be found several false QRS events along the same cycle and if we have a longer length the algorithm will not found all true QRS events. In this work it has always used a vector with length 12.

C. Detection of ECG Events

To identify the electrocardiogram events we will use correlations and the principle that one wave has two parts: one ascending and other decreasing. This is guarantee by the preprocessing using the filters described before.

To identify the different events and cycles, we chose to make the detection cycle by cycle.

We began by creating a variable *j* which would advance a number of samples for the cycle being entirely represented. The variable *j* was initialized in a position inside the first complete cycle.

We begin by numbering each cycle before the different complexes. We used a variable named *ciclo* and was initiated at 0. Next, we selected a segment (*s3*) of the signal with length of the period P plus 20%, in order to guarantee the entire next period.

```
ciclo=ciclo+1,
s3=s(j:j+round(P*1.2));
```

The next step was to detect the cycle period in which we were to identify the events of the ECG. For this, we seek the maximum value and its index in *s3* segment. If it is the first cycle, then the period is determined by the difference to the beginning of first QRS complex (144). However, if it is not the first cycle then the period shall be the index of maximum amplitude plus 50 (to guarantee one complete period). Later, the end period position will be recalculated. The period in second is determined dividing the number of samples by the sampling frequency (Fa).

```
[pico,indp]=max(s3);
        if ciclo==1,
         periodo(ciclo)=(indp+j-144);
        else
         periodo(ciclo)=(indp+50);
        end
periodo_s=periodo(ciclo)/Fa,
```

The first event to be detected was the R point. This point is just the maximum point previously determined. Next step consist in adjust the end of our search area adding to the index *j* the R-point approximation of 90% over the period.

```
  s2=s(j:j+indp+round(P*0.9));
```

Behind the R point we have the P wave, more precisely the end of P wave. The way found to make its detection was by correlation, this is carried out in exactly the same way as explained earlier, what differs is only the vector for comparison. Within the specified condition we just have to inform that the maximum correlation is found between the start of the cardiac cycle and the R point. We have to add the variable j, because this variable places in the entire signal.

```
[pic3,indmax3]=max(xc3(j-1:pont_R+j-1));
  fim_P=indmax3+3
```

The correlation procedure was also used to find the point Q, and the search area goes from the end of P wave to the R point. The point that marks the beginning of the T wave also has found by the correlation with a margin beginning at the point S to the result of the value of the period plus a number that allows us to look without that section of the signal ends.

For the other electrocardiogram events, the reasoning was search for local peaks and valleys.

So, we can detect an event through the end of an ascent or a descent. Thus, with reference to the end of the P wave signal backwards in that we found a rise and found that when finished this will give us the point at which the P wave is maximum.

In opposite way if the point is higher than previous one, and this was repeated some points, we are witnessing a rise. Obviously one begins to decrement in the section on the end of the P wave.

```
i=fim_P-1;
while ~((s2(i-3)<s2(i-2))&&(s2(i-2)<s2(i-
1))&&(s2(i-1)<s2(i))),
                  i=i-1;
end
max_P=i
```

This method of ascent is also used to detect the maximum of the T wave. To do this we must move forward from the point R and started looking for him after the start of the T wave (we will see later on how we detect). But in place of decrement will be increment.

```
i=max_T+1;
    while ~((s2(i+2)>s2(i+1))&&(s2(i+1)>s2(i))),
i=i+1; end
fim_T=i;
```

This procedure is used to detect the S and the end of the T wave, using the increment instead of decrement.

```
i=max_P-1;
    while ~((s2(i-2)>s2(i-1))&&(s2(i-1)>s2(i))),
      i=i-1;
    end
in_P=i
```

To advance to the next cycle, only *j* is going to be changed to R point plus previous *j* summed over a value that gives a safety margin that was 50 samples.

```
j=j+pont_R+50;
```

VI. Results

In Fig. 18 we can see all points of interest marked in a single cycle, and Fig. 19 we can see that these points are marked in all cycles.

A. Marking of Complexes and Intervals of ECG

To mark the complex and ranges were used lines that marked its length, beginning and end.

The horizontal lines are marked by the plot command. It starts by marking the coordinates of x and y and color. After using the text command also marks the coordinates of the axes and writes the text. Finally, the vertical lines show the same process that the horizontal, but still adds the information of the type and thickness of line.

```
plot(in_T+j-1:fim_T+j-1,-65*ones(1,fim_T-in_T+1),
'k'),
text(in_T+j-1+(fim_T-in_T)/2,-65-10,'T')
line([in_T+j-1;in_T+j-1],[0-70;0+10],'color','k',
'Linewidt',0.5,'Linestyle',':')
line([fim_T+j-1;fim_T+j-1],[0-70;0+10],'color',
'k','Linewidt',0.5,'Linestyle',':')
```

Fig. 20 shows one cycle with all the complex and defined intervals. In Fig. 21 the complex and events over several cycles can be seen.

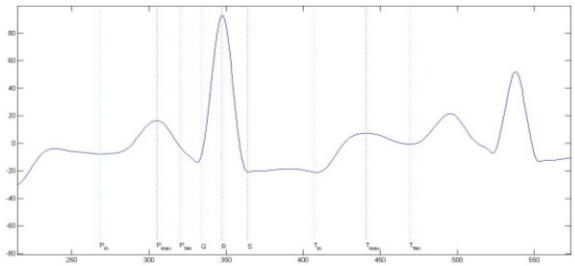

Figure 18 - Electrocardiogram events in one cycle.

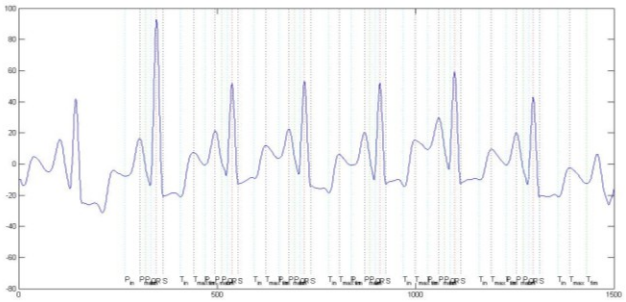

Figure 19 - Electrocardiogram events in all cycles.

Also we calculated the time in seconds of each complex and each interval. It was performed by the difference between end and beginning positions divided by the sampling frequency.

At the end of every cycle was also calculated the mean duration of each event, in seconds.

```
Dur_P(ind)=(fim_P-in_P+1)/Fa;
Med_Dur_P=mean(Dur_P)
```

VII. CONCLUSION

The paper presents an algorithm used for ECG without diseases events detection. This algorithm is part of a system used to help the diagnosis of pathologies by the ECG. This system can be used as a serious game for practice.

The paper stars listing several different patterns of ECG and cardiac diseases, presents a preprocessing of the ECG to remove noise, and then presents the details of the algorithm.

The noise removal processing guarantees that the signal has clear increases and decreases due to the events and has no small oscillations in these curves.

The algorithm starts by finding the periods, and then using a technique based in the correlation between events and selected parts of the ECG signal, and finding peaks and valleys identify the searched points in a sequence.

In summary, the reference point was the point R, from this point was determined the Q point and the end of P wave. Through the end of P wave we find the maximum point and then the beginning of the P wave. These points were calculated by decrements. The following points are presented in ascending order in which they were determined were detected by increments: S point, the beginning, the maximum and the end of the T wave.

In future, this algorithm would be improved so that it can run on any type of ECG signal. For that, this program would have to be more robust technique in order to detect events considering that some events are missed in the ECG.

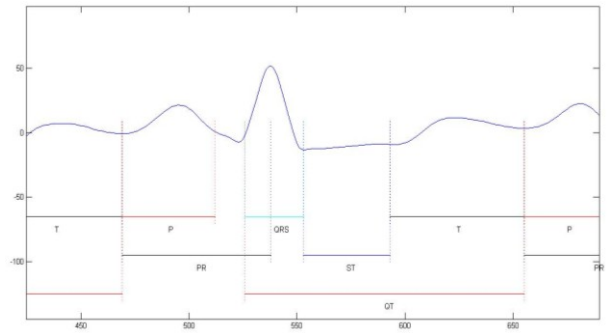

Figure 20 - ECG signal with all the complex and intervals in a cycle.

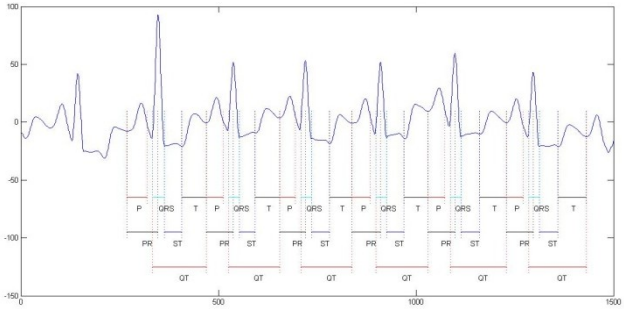

Figure 21 - ECG signal with all the complex and intervals in all cycles.

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