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DETECTION OF CHEST COMPRESSIONS IN RESUSCITATION DATA

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ABSTRACT

Cardiac arrest is the most common reason of death for thousands of people every year. Immediate treatment of cardiac arrest can reduce the rate of death. The treatment of the cardiac arrest involves cardiopulmonary resuscitation (CPR) providing chest compressions and ventilations, medicine and defibrillator to analyse the heart rhythm and give an electric shock if the rhythm is shockable, this kind of defibrillator called automated external defibrillator (AED) . A good quality of CPR can increase the survival rate, but in practice the quality of CPR falls rapidly after short time and not keeping the recommendation of guidelines for CPR.

In order to improve the quality of CPR, it has been suggested to improve the automated external defibrillators (AED) with the ability to check the quality of CPR and give a feedback if it falls. To achieve this improvement it is important to know when the CPR is ongoing, in other words it will be very useful to detect the chest compressions and ventilations in the heart rhythm such that the AED can analyse the information of the detection to give a feedback to improve the CPR when it is needed. In this study we will try develop a detection system of the chest compressions. A method to annotate the compressions will be developed also to make the reference (annotations) of the chest compressions that allow us to evaluate the performance of the detection system. The pressure information which is measured by sensor on an extra pad of the defibrillator is used for the annotation of the chest compressions and the thoracic impedance signal is used to develop the detection system. Performance of the detection system based pressure/Impedance/ECG signal is evaluated and presented in this thesis.

PREFACE

First of all, I would like to thank my supervisor, Associate Professor Trygve Eftestøl for following and helping me during this study. Thanks for support and guidance, and for the helpful feedbacks during this work.

Thanks for my colleagues and for with student Jan Heldal for discussing and comments.

I would like also to thank my parents for encouragement and pushing all the time.

Finally I would like to thank my husband and my son for patience and support.

1. INTRODUCTION.

Every year more than 5000 persons getting cardiac arrest (heart stop) in Norway. Two of three of these persons are out of hospital. It is estimated that each year between 400000 and 460000 people die of sudden cardiac arrest in an emergency department or before reaching a hospital, which accounts for over 60% of all cardiac death. [10].

Many of those who die of sudden cardiac arrest could be survived if they got correct CPR, medicine and defibrillation of the heart.

The basic life support (BLS) which means the immediate CPR with medicine can helping with surviving the cardiac arrest.

There is increased attention to the important of reducing time without blood flow from chest compressions during cardiopulmonary resuscitation (CPR). [7].

The quality of cardiopulmonary resuscitation (CPR) in out-of-hospital cardiac arrest is not held according to the recommendation of guidelines for cardiopulmonary resuscitation (CPR). This is analysed and presented in many publications. [11]. The publication shows that the quality falls very quickly even with health personnel which reduce the chance of survival. The problems are the long breaks in the chest compressions and ventilations, the low rate of the chest compressions, the ratio between chest compressions / ventilations and the depth of the chest compressions.

In order to improve the quality of the CPR, it will be very important to know when / where the chest compression in a measured signal.

The thoracic impedance signal can be measured via the defibrillator pads using a modified automated external defibrillator (AED) which can analyse the signal and give a feedback when the quality of the chest compressions (depth or rate) is not held, if it could be possible to detect the chest compressions. Detection of the chest compressions is not easy in the thoracic impedance which is very sensitive to the movement and contains noise while using the pressure signal which is provided by pads on the chest measuring any pressure on the body, can indicate the time of the pressure and considered a not noisy signal comparing with the thoracic impedance.

In this study we will develop a semi automatic method to detect the chest compressions using the pressure signal which will collect the reference (annotations), we will develop this semi automatic method to a full automatic method to detect the chest compressions and the performance of the full automatic method will be evaluated by apply it on pressure, thoracic impedance and ECG signal during CPR and using the information (reference) from the semi automatic method.

1.1 Functionality and objective

This motivation of detection or removing the CPR artifact in ECG is to increase the chance of surviving a cardiac arrest by improve the quality of the CPR. By removing the artifact the AED will be able to take a reliable signal analysis while the CPR is going without needing to a break. The impedance signal can indicate the compressions and ventilations during CPR because of its sensitivity of movement and can be a base to detection system of the chest compressions in order to measure the quality of CPR.

The pressure signal, which is done available by sensor measuring the pressure on the chest when the defibrillator connected to the chest of patient, can be a good base for determining the compressions.

The main focus of this thesis is:

- Develop a pressure based semi automatic method to determine where the compressions are, thus make a reference (annotations) of the chest compressions.
- Develop an automatic detection system based on the semi automatic method to estimate the compressions.
- Evaluate the performance of the method based on pressure, thoracic impedance and ECG signal.
- Improving the performance of the method by using several threshold values.

1.2 Thesis outline

This thesis consists of the following chapters:

Chapter 1 is the introduction to introduce the work in this thesis and get a general overview over the problem and the objective of this study.

Chapter 2 gives a briefly medical background, a short presentation of the heart, cardiac arrest, heart rhythms during cardiac arrest and a basic CPR. A short description of the different signals used in this study is given also in this chapter.

Chapter 3 describe the human data used and made available for this study including pressure, thoracic impedance and ECG signal.

Chapter 4 describe the methods developed in this thesis. The semi automatic method is described and a plot illustrates the principal used here. The full automatic method (detection system) is represented and its performance evaluated in this chapter.

Chapter 5 presents the result of the method / system developed in this work during a CPR. The result is discussed here.

Chapter 6 represents the conclusion of the methods done in this thesis.

Chapter 7 is an appendix consists of the matlab code, functions and script, developed in this thesis.

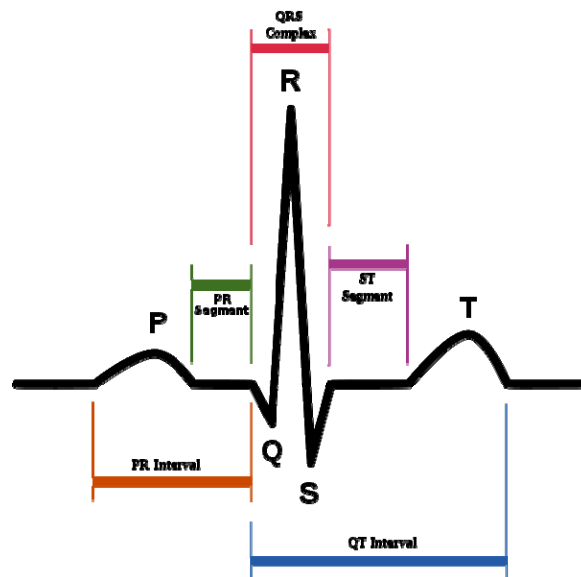
Chapter 8 present some of the references used under working with this study.

2. BACKGROUND

In this chapter we present the fundamental medical background of this work. This will include the physiology of the heart, cardiac arrest, the CPR and the quality of the CPR.

2.1 The heart

The human heart has a principally composed of cardiac muscle and connective tissue pumping blood through the body. The average human heart is beating 70 beats per minute and the normal heart rhythm is sinus rhythm. [18].



2-1 The normal sinus rhythm for a human heart as seen on ECG. [18].

2.1.1 Cardiac arrest

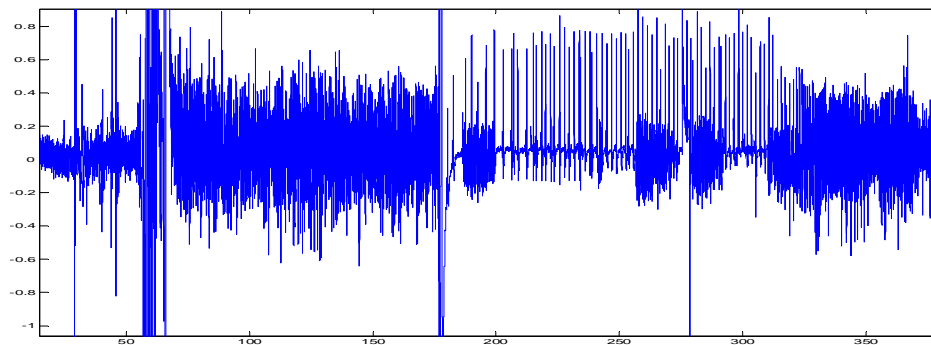
The Cardiac arrest is the abrupt loss of heart function in a person who may or may not have diagnosed heart disease. The term "heart attack" is often mistakenly used to describe sudden cardiac arrest. While a heart attack may cause cardiac arrest and sudden death, the terms don't mean the same. Heart attacks are caused by a blockage that stops blood flow to the heart. [1].

Cardiac arrest is caused when the heart's electrical system malfunctions. In cardiac arrest death results when the heart suddenly stops working properly. This is caused by

abnormal, or irregular, heart rhythms which called arrhythmias. [1]. The arrhythmias of the cardiac arrest can be analysed by AED to shockable or unshockable rhythm. The unshockable rhythm is treated by CPR.

2.1.2 Electrocardiogram (ECG)

An ECG is simply a representation of the electrical activity of the heart muscles as it changes with time, usually printed on paper for easier analysis. Like other muscles, cardiac muscles contracts in response to electrical depolarisation of the muscle cells. It is the sum of this electrical activity, when amplified and recorded to just a few seconds that we know it as an ECG. [9].



2-2 ECG signal for procedure 4 in the database

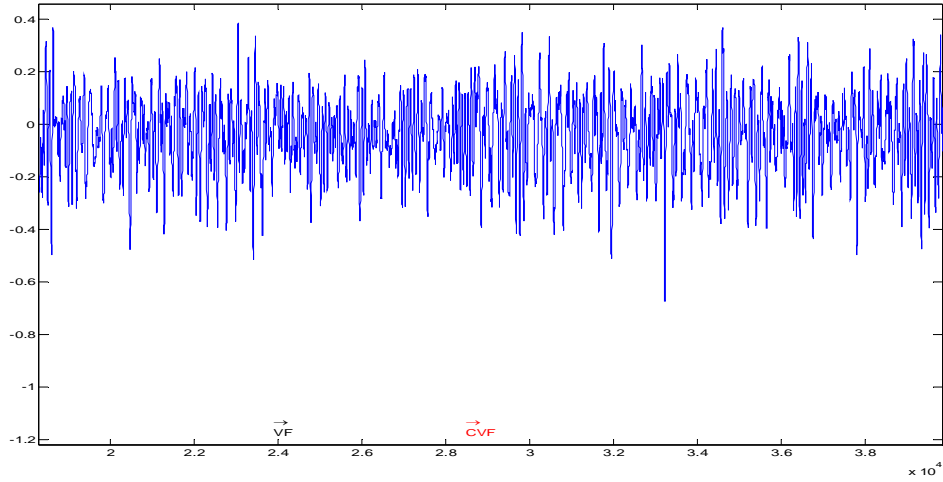
The chest compressions create noise in the ECG signal and should be stopped while the AED analyses the signal. This break in the CPR increases the chance of damaging the brain.

2.1.3 Heart arrhythmias

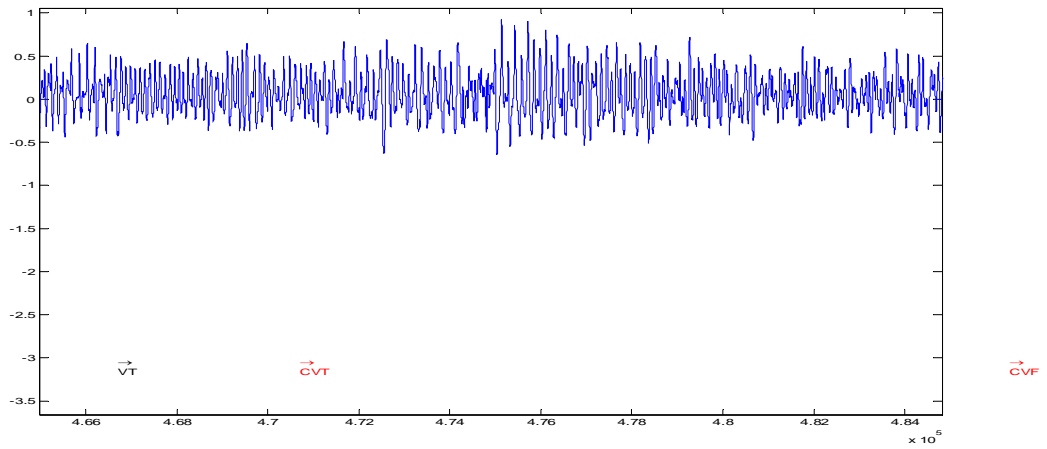
In cardiac arrest, the heart stops the normal pumping of blood and the normal sinus rhythms of ECG will be changed and called as mentioned before an arrhythmia. There are four main groups of arrhythmias.

- Ventricular fibrillation (VF): VF is a condition in which there is uncoordinated contraction of the cardiac muscle of the ventricles in the heart, making them quiver rather than contract properly. Ventricular fibrillation is the most commonly identified arrhythmia in cardiac arrest patients. [4].
- Ventricular tachycardia (VT): VT is a fast heart rhythm that originates in one of the ventricles of the heart. This is a potentially life-threatening arrhythmia because it may lead to ventricular fibrillation, asystole, and sudden death. [5].
- Asystole: Asystole is a state of no cardiac electrical activity. This arrhythmia is often treated with chest compressions and ventilations.
- Pulseless electrical activity (PEA). PEA occurs when there is an organized electrical activity but there is no pulse.

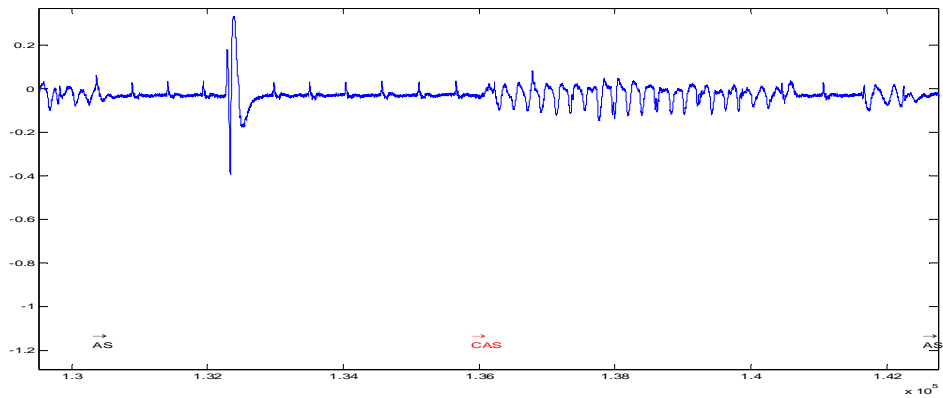
Figure 2-3, 2-4, 2-5 and 2-6 show different arrhythmias treated by compressions. The figures show ECG signal labelled with the type of the heart rhythm. Place of the labels represent the start of the rhythm. The red colour of the label indicates the starting of the compressions and the label starts with c (from compression).



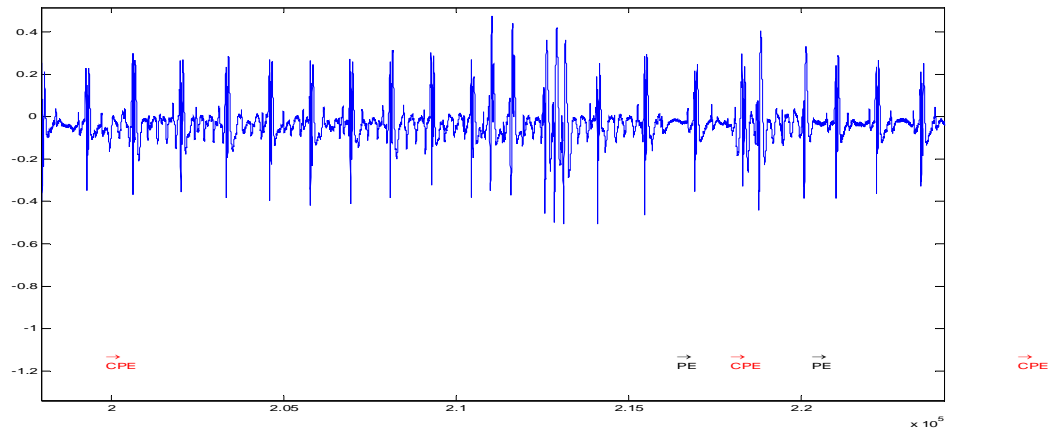
2-3 VF arrhythmia followed by compressions in ECG



2-4 VT arrhythmia followed by compressions in ECG



2-5 AS arrhythmia followed by compressions in ECG



2-6 PE arrhythmia followed by compressions in ECG

2.2 The thoracic impedance signal and Pressure signal

The electrical impedance of biological tissue is found by passing a current through the tissue and measuring the voltage drop. Ohm's law can then be used to find the impedance. The impedance changes with the distance between electrodes, and with redistribution and movement of fluids contained in the tissue. [6]. The impedance signal is sensitive to the movement, the CPR cause artifact in analysing the heart rhythm. The problem is that the rescuer is not following the recommendation of guidelines for the CPR which makes it more difficult to detect.

Pressure signal is the information we get from the sensor fitted on the extra pad of the defibrillator. The sensor is sensitive to the movement of the chest and delivering the information on a card fitted to the defibrillator.

2.3 CPR and quality of CPR

Cardiopulmonary resuscitation (CPR) is an emergency procedure which is performed in an effort to manually preserve intact brain function until further measures are taken to restore spontaneous blood circulation and breathing in a person in cardiac arrest. It is indicated in those who are unresponsive with no breathing or abnormal breathing. It may be performed both in and outside of a hospital. [2].

The immediate CPR is very critical to avoid damage in the brain and to help heart to have a shockable rhythm, or in seldom cases to regain the normal rhythm.

CPR involves chest compressions and ventilations with ratio 30:2.

- Chest compressions: The chest compressions are necessary to provide the vital organ with circulation of blood. The chest compressions are done by pressing the chest between the breastbones from 4 to 5 cm. These compressions should be repeated with rate of 100 compressions per minute.
- Ventilation: The manual ventilation is done by mouth to mouth method to provide the lungs with oxygen.

2.3.1 Factors affecting the efficacy of CPR

The most important factors that affect the efficacy of CPR are listed below:

First: The quality of the chest compressions should be good, it means:

- Correct frequency: Rate of the chest compressions which is recommended to 100 compressions per minute, earlier publications shows that even the professional health persons are not able to keep the correct frequency; therefore, it is recommended that persons change every third minutes if it is possible.
- The depth of compressions should be between 4 and 5 cm.
- Chest compressions/ventilations ratio should be 30:2.

Second: Breaks, unnecessary breaks in the compressions leads to bad blood circulation and results to damage of the brain within 4 to 5 minutes. It s very important to continue the CPR without breaks.

Even with the health trained personal, the quality falls and the chance of survival a cardiac attack will be reduced.

Detection of the compressions/ventilations can help us to analyse the quality of the CPR and improve it.

The AED could be improved, to automatically analyse the quality of the cardiopulmonary chest compressions / ventilations and give a feed back if one of the factors affecting the efficacy of the CPR falls, if the detection is made possible.

2.4 Problem formulation

The immediate treatment of the patients with cardiac arrest with a good quality of CPR can increase the rate of survival. The improvement of the CPR can spare many hearts and protect the tissue of the brain from damage. Unfortunately the quality of CPR is not held according to the recommendations of the guideline of CPR. The main problem here will be to detect the chest compressions to in order to be able to give a feedback when the quality of CPR falls.

For this problem a detection system of the chest compressions is developed and a method to annotate the compressions and make a reference of the chest compressions. An evaluation of performance of the detection system is presented also in these papers. The pressure signal which is measured by sensor on the extra chest pad of the defibrillator is used for the annotation of the chest compressions.

3. HUMAN DATA

Series of adult patients with out of hospital cardiac arrest with all rhythms treated by CPR in Stockholm, Sweden, London, England, and Akerhus, Norway, between March 2002 and October 2003. The defibrillators recorded chest compressions via pad fitted with an accelerometer and ventilations by changes in thoracic impedance between the defibrillator pads, in addition to standard event and ECG recordings. The defibrillators were fitted with an extra chest pad to be mounted on the lower part of the sternum with double adhesive tape. This chest pad was fitted with a pressure sensor in addition to the accelerometer. The heel of the rescuer's hand was placed on top of the chest pad and movement of the chest pad was considered equal to that of sterna movement during chest compressions. To avoid registering movements of the entire patient as chest compressions, only movements of the sterna chest pad with a parallel compressions force more than 2 kg were used in the automated analysis.

Data from each resuscitation episode were collected in 2 data cards; 1 standard card collected ECG signals, time and events and a second card fitted especially for recording signals from the extra chest pad and thoracic impedance between the defibrillator pads. The row data consisted of time line and events. The ECG, thoracic impedance and the values from the extra chest pad, all sampled at 500 HZ.

This data made available for this study, our focus will be on the pressure signal (obtained from the sensor of the chest movements on the extra pad) and the thoracic impedance signal. The first 40 procedure is used to make a reference of the compressions.

4. METHODS

In this Chapter we present the methods developed in this study. The development is presented also in matlab code attached to this thesis.

The main job in this chapter is developing a semi automatic method based on the pressure signal to make reference for the chest compressions, and develop a detection system to detect the compressions in pressure and thoracic impedance signal.

4.1 Processing the signal.

All database we used are for adult patients getting out of hospital cardiac arrest and treated with CPR. Treatment with CPR is introducing a noise in the recording (measuring) heart rhythm. When we want to detect the compressions, the ventilations cause noise in the channel we use. We filter the channels used in developing the methods by a band pass filter from 0.5 to 30 HZ to eliminate the noise caused of these ventilation and the noise of fibrillation the heart (high rate of beats) which could detected as compressions.

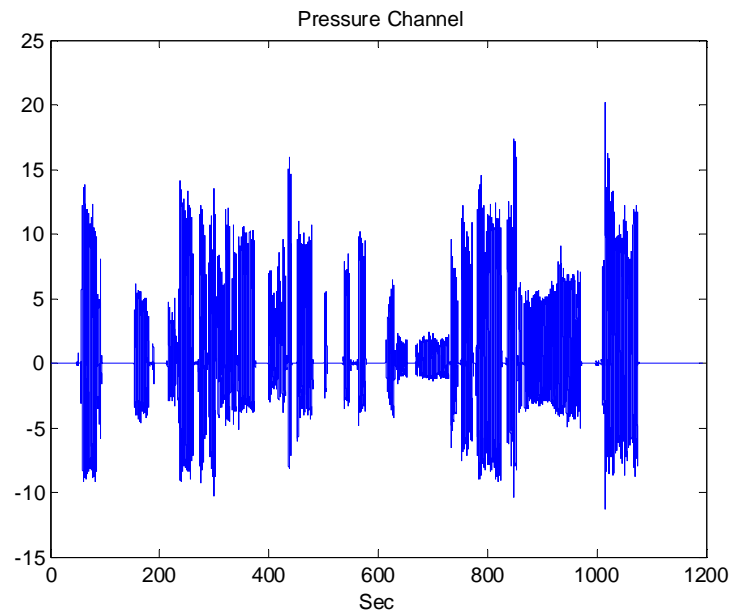
4.2 Annotation of CPR artifact

The main focus here is to develop a method for annotation of chest compressions. The annotations this method will provide us will be later the reference to evaluate an automatic detection algorithm of chest compressions. The pressure channel will be used for the finding annotations.

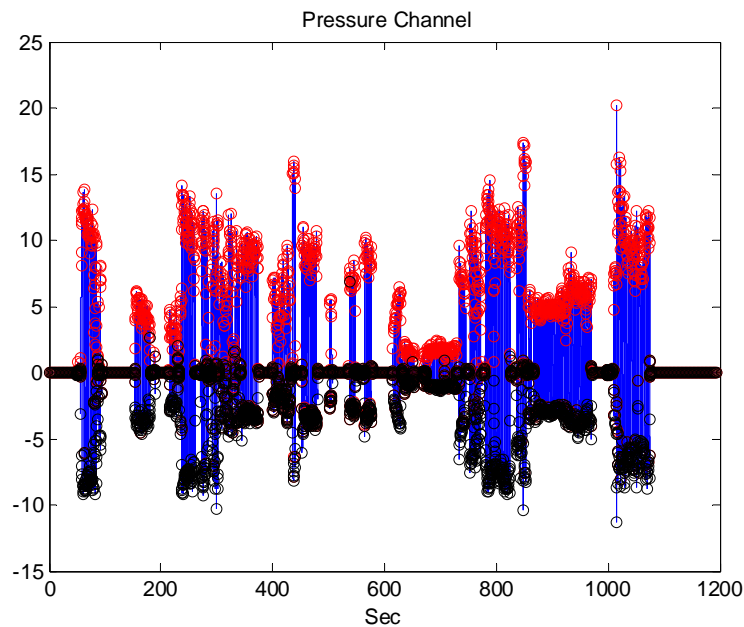
4.2.1 Development of the method

To find the tops points in the signal will be a good start. The top points are the local maximum in the pressure and occur when the difference between the value of every location and the previous location changes the sign from positive to negative or zero. Top points can be detected by collecting the indexes of these locations. In a similar way, the bottom points are the local minimum in the pressure and occur when the difference between the value of every location and the previous location changes the sign from negative to positive or zero. Bottom points can be detected by collecting the

indexes of these locations or by finding the tops of the pressure signal multiplied with minus.



4-1 plot of pressure channel



4-2 pressure channel with annotations of the tops and bottoms before visualise the method

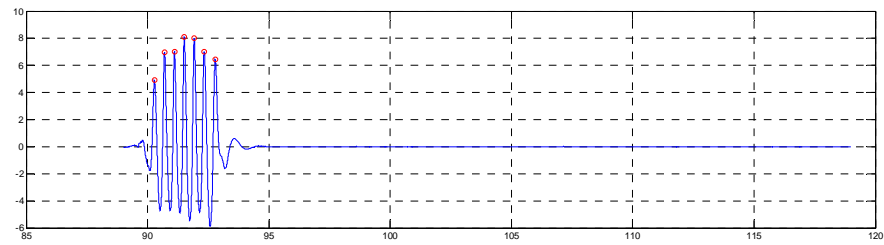
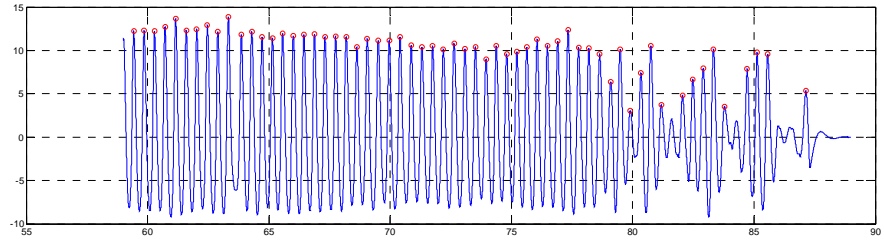
The previous two figures show the pressure channel for one of the patients and the same pressure channel with annotations, respectively. The top points are viewed as red rings and bottom points as black rings. This plot doesn't make it easy to see if we get right or wrong annotation. It will be necessary to visualise the method with "shorter" parts of the signal such that it can be easy to see and decide.

4.2.2 Visualise the method

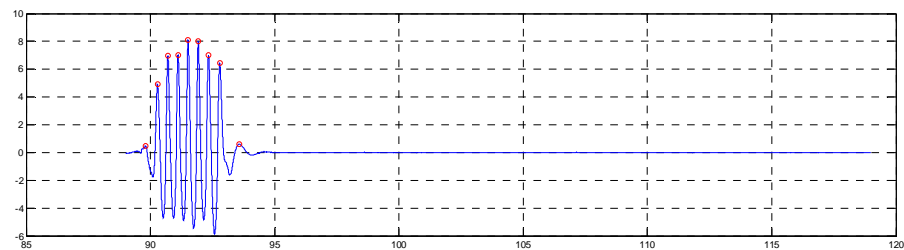
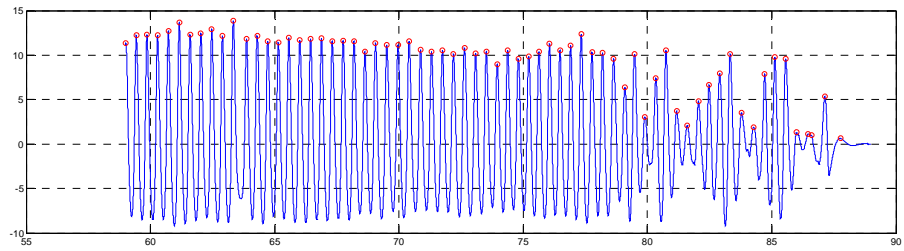
The method is visual, it means that it should be possible by watching the figure to judge if there are compressions or not which is not easy if the whole channel has been used, in order to satisfy this criterion the signal will be divided into many windows, every window will represent one minute except the last window, and the detection will be done for every window separately. In this way it will be possible visual to decide if all the compressions are detected or not. The method is half manually; it means that it offers the possibility to change one or more parameter after every detection if the result is not as expected. Actually it is possible to change the parameters for unlimited times until the result is accepted, and then the accepted result will be saved.

The first parameter that can be changed are the amplitude, which is the value between a top point and next bottom point. The second parameter is the minimum accepted time between every two consecutive top points.

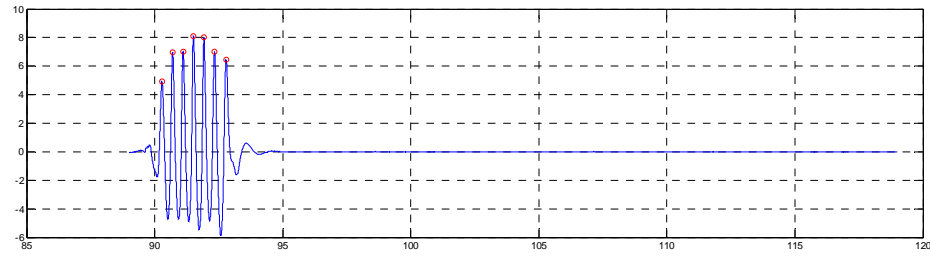
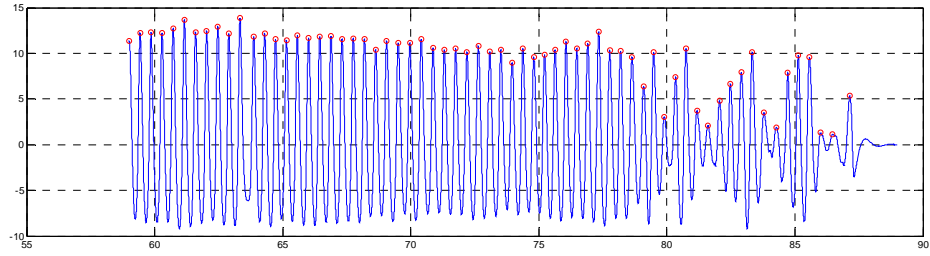
There is an overlap between every window and previous window with one second due to processing of the detection at the end/edge of the window. Matlab code is available for more information / details.



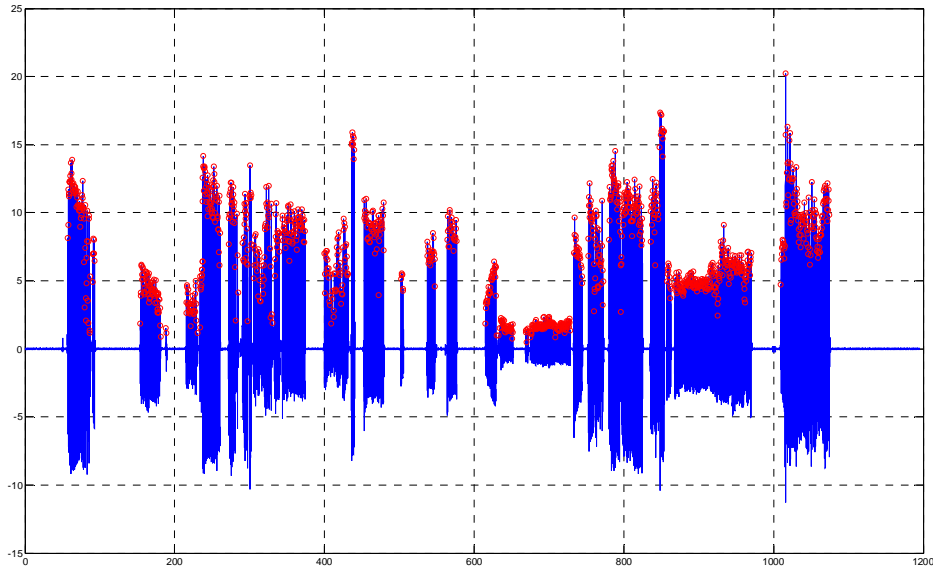
4-3 Annotations for one window with using default value of the amplitude



4-4 Annotations for one window with using too small value of the amplitude



4-5 Annotations for one window with using suitable value of the amplitude



4-6 The sum annotations of a procedure of the pressure channel

4.3 Detection of the CPR artifact

In this chapter, a full automatically detection system will be developed to estimate the detection of the chest compressions. The main goal here will be to evaluate the performance of this automatically method when it is applied on the different available channels.

4.3.1 Development of the method

The basic principle of finding the tops and bottoms in the signal as described before is used here also, the main difference here is in developing and processing of the found tops. This detection system doesn't give the user the possibility to choose the parameters. The detection of the compressions is done on whole the signal without divide it to many small windows.

Estimation of the parameters is done according to the thoracic impedance signal and applied to evaluate it to the other channels.

The main processing here is the frequency in the compressions. The compressions frequency supposed to be 100 compressions per minute, which means 1.6 compressions per second. In out-of-hospital cardiac arrest, the person who performs the chest compressions might not keeping the recommended rate due to stress and other circumstances. The rate can be more or less than 1.6 compressions per second. It is not easy to decide if the rate can increased to 2 or 3 compressions per seconds but it is quite reasonably to say that 4 compressions per second, which means 240 compressions per minute, is too much to be a manual compressions. A detection of tops that has an interval less than 0.25 seconds, which is equal to more than 240 compressions per minute (4 Hz), is not a detection of compressions.

A "for" loop is used to check the interval between every two followed tops. If the interval is less or equal to 0.25 second, the code will check the value of the top. The biggest value will be kept while the smallest value will be eliminated.

A top without a sequence of compressions is eliminated.

Minimum amplitude of the acceptance tops as compressions is necessary here. In the half manually method we could adjust this value in every detection, but here in this

method we don't have this possibility. Impedance signal contains more noise than pressure signal that can affect the amplitude. A default amplitude is used by using the information in compressions depth channel which gives an indicator of how the value of the tops in impedance signal can be changed when there compressions.

The estimated detection of the compressions is collected in a cell array in matlab. The method is programmed such as to collect the estimated detection for every procedure in a cell array in the same position as to corresponding reference. It means if the reference to a procedure is for an example in the second row and the first column in the cell array for references, so the position of the estimated detection, for the same procedure in the cell array for estimated detections, will have the same position as in references array. Matlab code is available for more information / details.

4.3.2 Performance evaluation

The performance of the method should be evaluated before any implementing.

In order to evaluate the performance, the reference data should be available.

Detector performance can be evaluated by estimating the following terms:

- P_d , the probability of a true compression being detected.
- P_f , the probability of a false compression being detected.

The probability of missed compression P_m is related to the probability true detection through $P_d=1-P_m$.

The estimation of those probabilities is based on the ratio that include:

- N_d , the number of correct detection of compressions.
- N_f , the number of false detection of compressions, or false alarm.
- N_m , the number of missed compressions.

The probability of true detection can be estimated from:

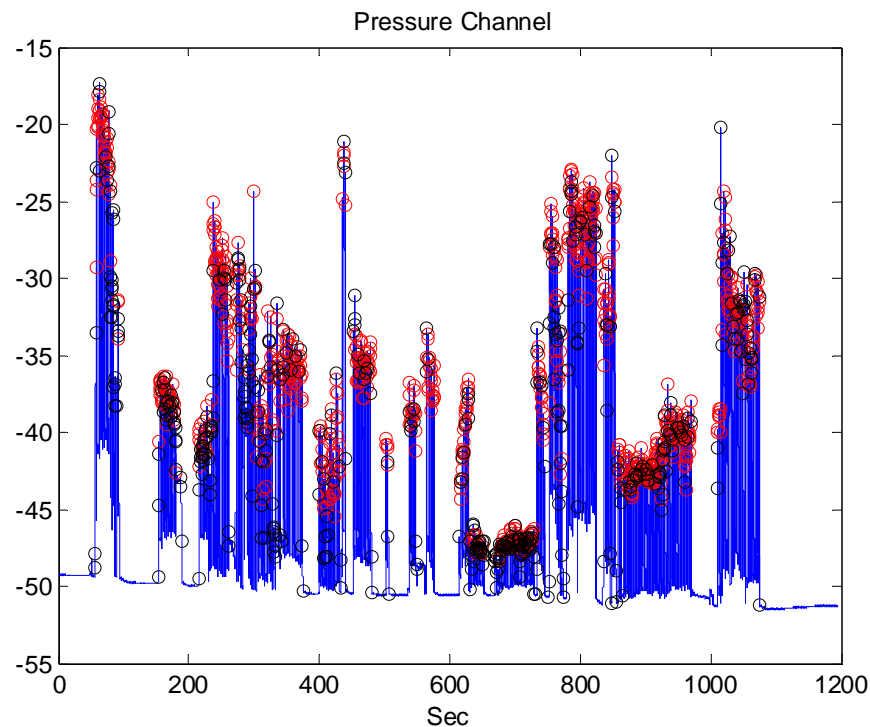
$$P_d = N_d / (N_d + N_m).$$

The probability of false detection can be estimated from:

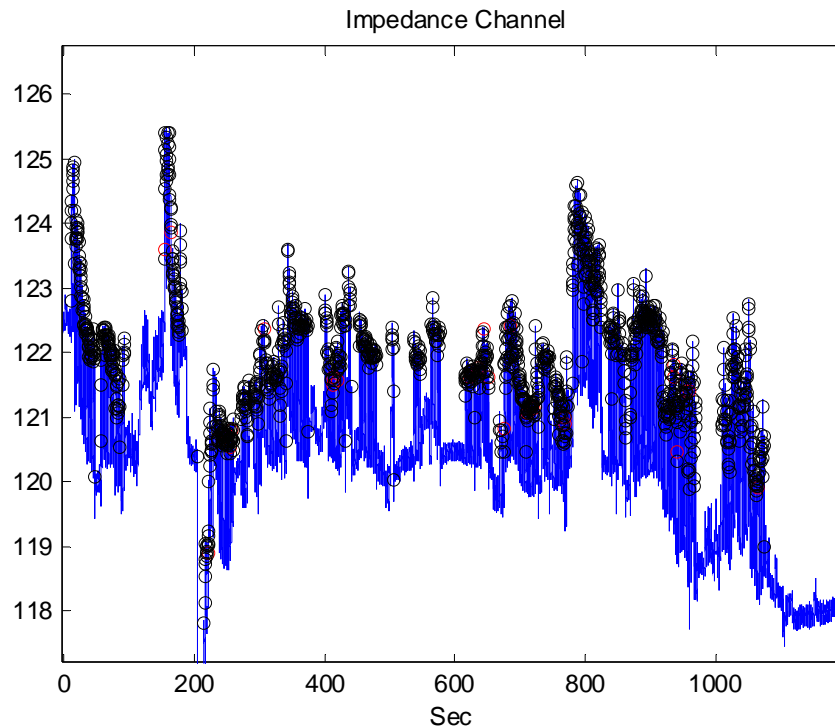
$$P_f = N_f / (N_d + N_f).$$

- The correct detections are found by a “for” loop that compare every reference with the estimated detections. If there is a match, the matched reference will be isolated, which will be the correct detection.
- The references which don't have a match are the missed compressions.
- The estimated detections which don't have a match are the false detection.

When we isolate those groups, we can compute N_d , N_f and N_m .



4-7 Row pressure channel with correct detection in red and false in black.



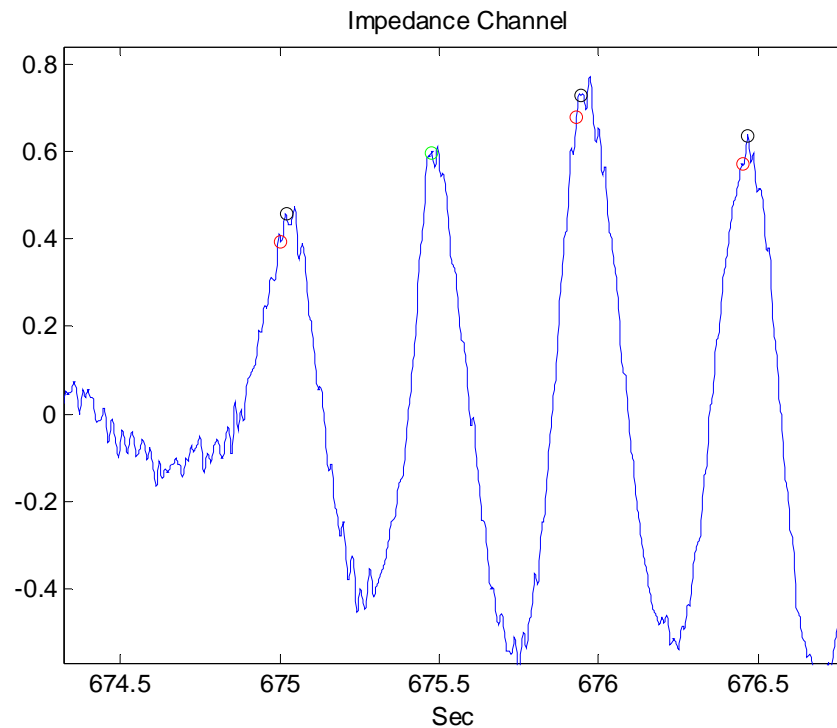
4-8 Row Impedance channel with correct detection in red and false in black, the figure shows the domain of the false detection.

The last 2 figures are not zoomed because the evaluation will depend on the calculations in matlab, while the semi automatic method is visualised.

4.3.3 Performance improvement

The performance of the method could be improved by modify the way the correct detection is found (isolated).

Figure 4-9 shows us missed detection plotted as red rings, the false detection is as black rings while the correct detection is in green. In fact many of the compressions that detect as false can be among the missed detections, thus correct detection, within a certain window . This window is defined as the absolute value between time of occurrence a false detection and missed detection.



4-9 False detection in black, correct detection in green and missed detection in red.

To implement this window in matlab code, the "for" loop is seeking a match between the references (annotations) and the detection, the "for" loop is said that a compression is detected when the difference between the time of estimated detection and the annotation (references) is within this certain matching window.

Threshold value assigned to this window, and can be tested to evaluate how it affects the detection performance.

5. RESULTS AND DISCUSSIONS

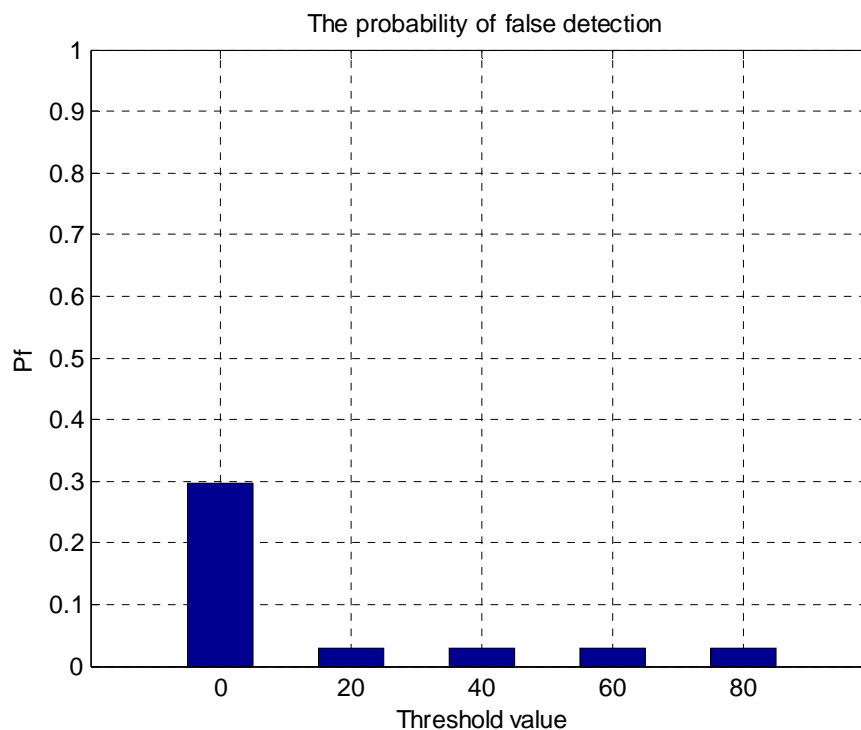
The result of detection system presented in section 4.2 is depending on the based signal. Basically it was developed for the thoracic impedance signal but it will be evaluated on the ECG signal. The semi automatic method based pressure is forming the reference. The semi automatic method based pressure signal is applied on the first 40 procedure in the available database.

5.1 Pressure signal

The detection system presented in section 4.2 based pressure signal seems to have sensitivity depending on the threshold window used to improve the performance.

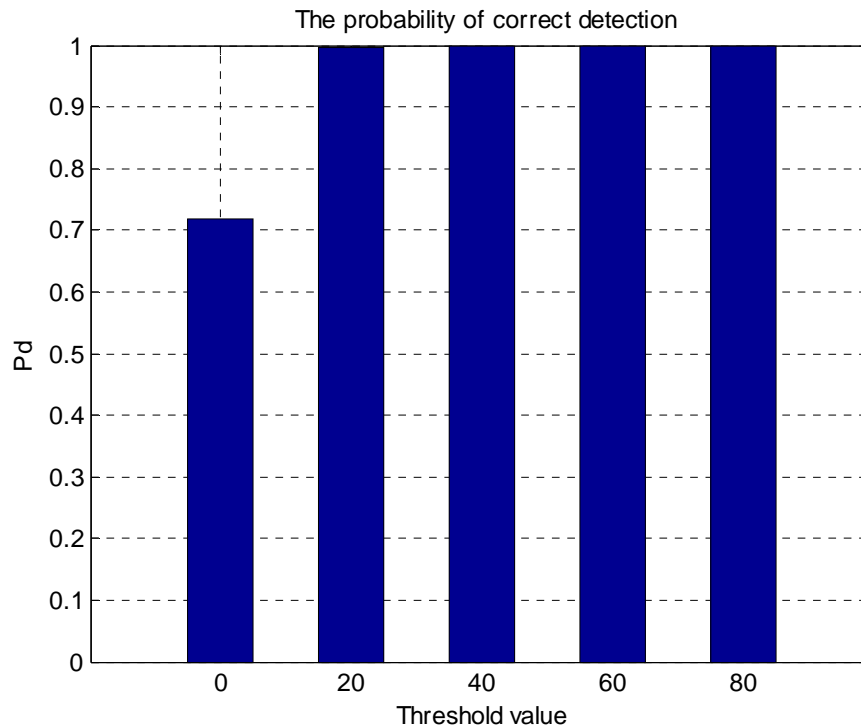
5.1.1 Result

The probability of false detection is 29.8% before the performance improved (threshold=0), while it reduced (improved) to 2.88% in the best case with using the threshold =80.



5-1 The probability of false detection based pressure signal for 5 threshold value

The probability of correct detection is 71.82% before the performance improved (threshold=0), while it increased (improved) to 99.97% in the best case with using the threshold =80.



5-2 The probability of correct detection based pressure signal for 5 threshold value

5.1.2 Discussion

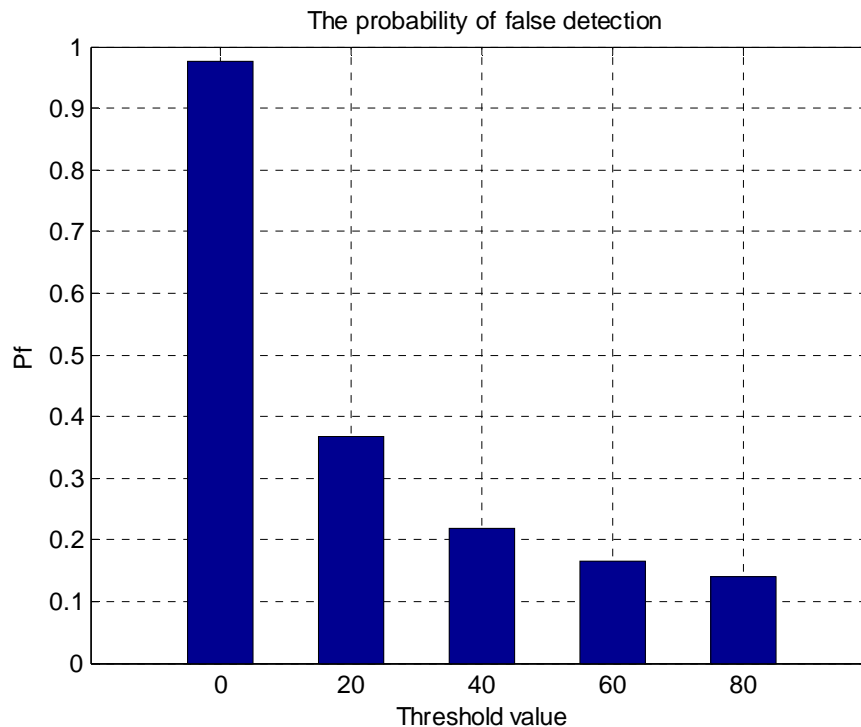
Actually this good result of correct/false detection is not surprising. The semi automatic method (reference) is based on the pressure signal and by applying the full automatic method, which is our detection system, on the pressure signal also so we expect a good result of correct detection because developing of the full automatic is based on the semi automatic method.

5.2 Thoracic Impedance Signal

The result presented in section 5.1 was expected. The training data used to develop the method, which is the data for pressure channel, is the same data used to evaluate it, but it will be quite interesting to present the result where the training data is the pressure channel and the evaluation data is the data in the thoracic impedance signal. It means result of the detection system based thoracic impedance signal (our reference is always the same based pressure).

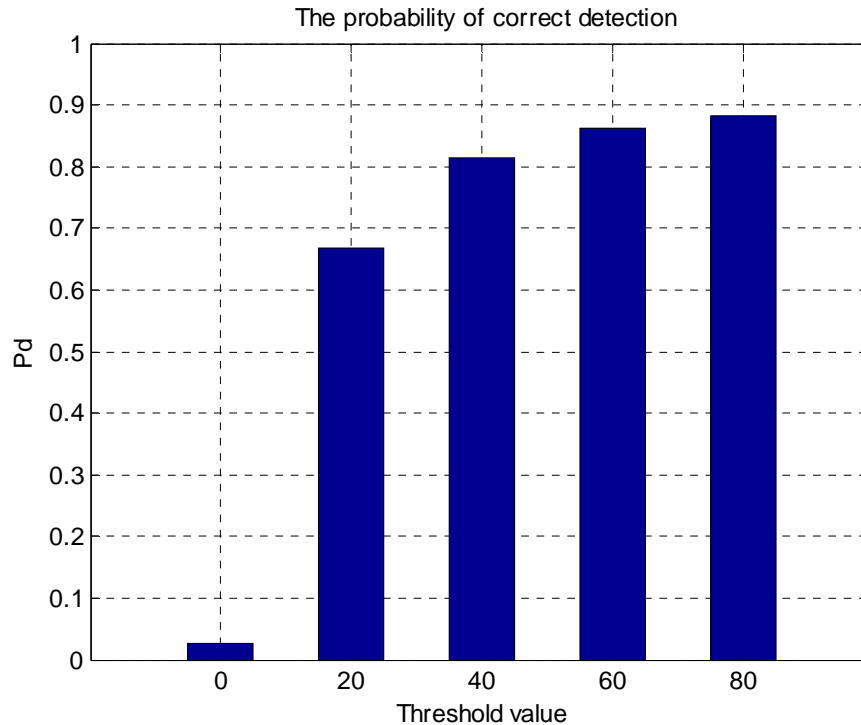
5.2.1 Result

The probability of false detection is 97.56% before the performance improved (threshold=0), while it reduced (improved) to 14.05% in the best case with using the threshold =80.



5-3 The probability of false detection based Impedance signal for 5 threshold value

The probability of correct detection is 2.55% before the performance improved (threshold=0), while it increased (improved) to 88.34% in the best case with using the threshold =80.



5-4 The probability of correct detection based impedance signal for 5 threshold value

5.2.2 Discussion

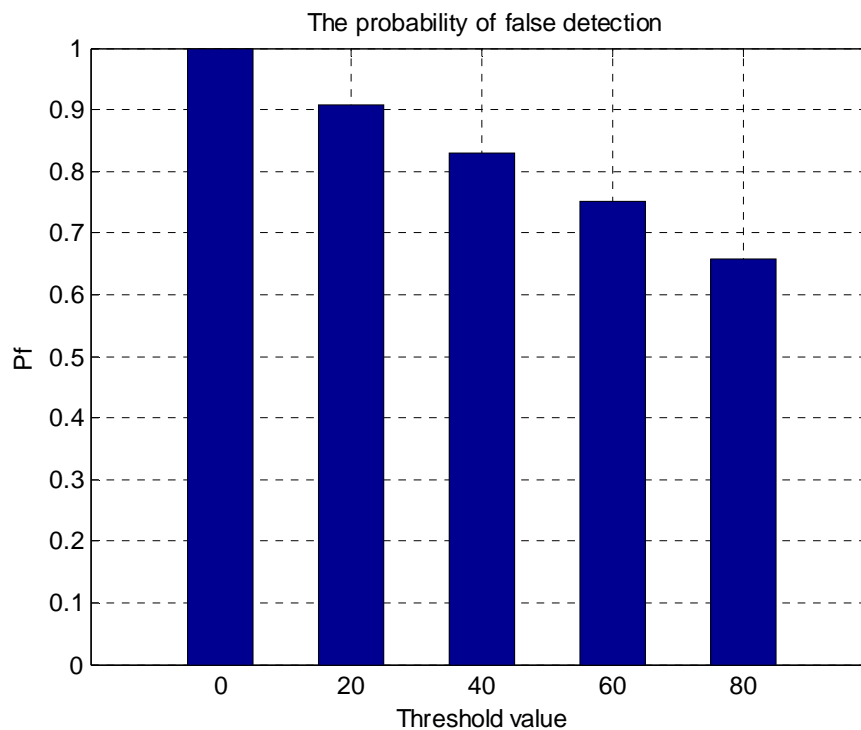
The correct detection is dramatically improved by using the threshold value (window) for the interval of the detection, but still missing compressions. The thoracic impedance is sensitive to movement which can give good indicate of the compressions but it is noisy signal comparing with the pressure signal that can leads to at noise is detected as compressions. A better filter for the impedance signal can truly affect the result, especially with reducing the false detection.

5.3 The ECG signal

The detection system can be applied on ECG signal also.

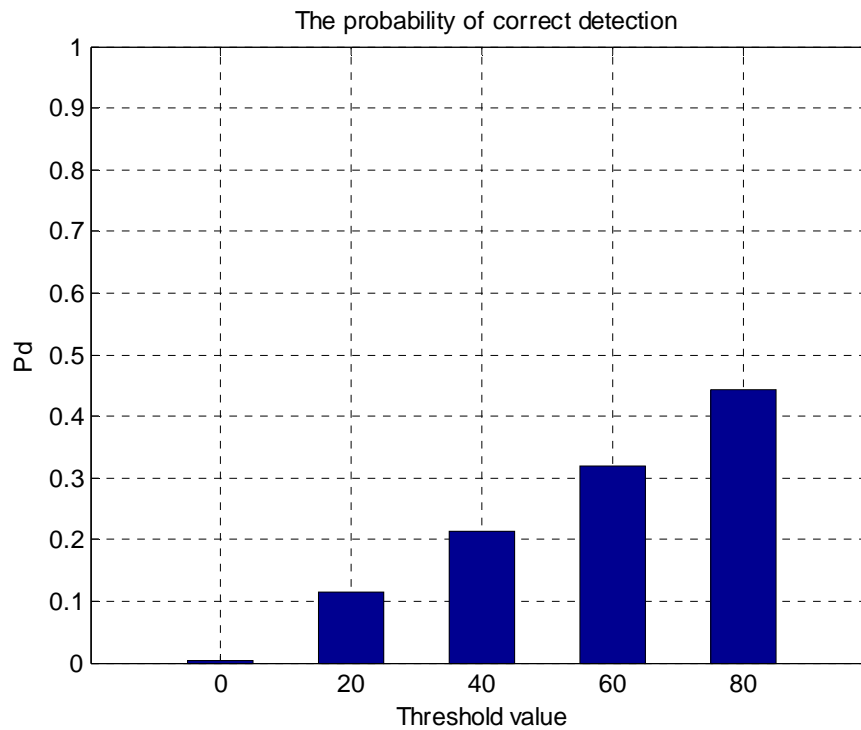
5.3.1 Result

The probability of false detection is 99.79% before the performance improved (threshold=0), while it reduced (improved) to 65.82% in the best case with using the threshold =80.



5-5 The probability of false detection based ECG signal for 5 threshold value

The probability of correct detection is 0.25% before the performance improved (threshold=0), while it increased (improved) to 44.28% in the best case with using the threshold =80.



5-6 The probability of correct detection based ECG signal for 5 threshold value

5.3.2 Discussion

The low probability of correct detection and the high probability of false detection is not what desired, even after the improved performance, the result is not good enough. In fact the ECG signal is much more noisy than the impedance signal. This signal should be differently processed from the way the impedance signal is done. Another filter (filter system) should be evaluated for this signal, and detection of the noise can affect the result.

6. CONCLUSION

The proposed detection system of CPR showed different performance. The detection system based on pressure signal was relative the best with probability of correct detection equal to 99.8%. The detection system based thoracic impedance signal was relative ok, the probability of correct detection could be better but the false detection should absolutely be less in order to say the system is usable. The goal is to get most possible correct detection and least false detection. A reprocessing of the impedance signal could be done by eliminate the frequencies that cause false detection but it is not enough. Analyse of the noise occurs in the impedance signal should be evaluated and process it again can have influence effect of the result which is not done because of the time limitation.

With using the ECG signal, the detection system is far from to be an ok system.

It is important to mention that the performance evaluation is done according to the reference we obtained by the semi automatic method, but even in the semi automatic method, the sensitivity is not is 100%. Some detection maybe not obtained or included in the reference or it is difficult to the eye to decide if some detections are really compressions. Leaning on the patient can affect the result of the semi automatic method, The detection there can be optimized also.

A disadvantage of the detection system and evaluation is the long time the script is using in matlab.

7. APPENDIX A

Matlab code.

7.1 Function fasit

```
function fasit( A )
%Fasit function is created to make a reference of the compressions in
%pressure signal.
% The function detect compressions in a pressure signal for a specific
% patient. The input of this function, A, is the patient number in the
% database.
%The function is used to make refernce in the first 40 procedure in the
%database.
%The function runs automatically and gives the user the possibility to
%change the parameters (amplitude and time between 2 followed compressions)
for every detection.

kodemappe
=('E:/masterThesis/Akuttmedisinisk_signalbehandling/Hjertekompresjon/');
datafiler= ('E:/masterThesis/Akuttmedisinisk_signalbehandling/data/');
load([datafiler 'longhw']);
a=arecs(A);
a=a{1,1};
if numel(a)== 0
    disp('The file is missing, please choose another number');
end
load([datafiler a '.mat']);
pressure=SIGNALS.pad_pressure.';

%%
%To eliminate the artifact due to the downsampling filter at the beginning
and
%at the end of the signal
pressure(1:20)=ones(1,20)*pressure(20);
L=length(pressure);
pressure(L-20:L)=ones(1,21)*pressure(L-21);

fs=500;
fn=250;
%T=1/fs;
%Pass band filter the pressure
nn=4;
f1=0.5;
f2=30;
Wn=[2*f1/fn 2*f2/fn];
nmf=fn;
[b1,a1]=butter(nn,Wn);
p=[pressure(1)*ones(1,nmf) pressure];
p=filtfilt(b1,a1,p);
p=p(nmf+1:end);

%%
len = length(p);
window=30000;
n1=1; n2 = n1+window;
minAmp = .3;
A=0.25;
```



```

Index=[];
while n1 < len
    if n2 > len
        n2=len;
        disp(['Length of last window = ' int2str(n2-n1)]);
    end
    p1=p(n1:n2);
    t1=(n1:n2)/fs;
    %call function detection to detect the compression for a certain
    %window.
    [t_ind tops] = detection( p1, minAmp, A );
    %eliminat a detection on the last edge of the window if it exists
    %and eliminat the first detection if it occurs on the first edge.
    if ~isempty(t_ind)
        if t_ind(numel(t_ind))== t1(numel(t1));
            t_ind(numel(t_ind))=[];
            tops(numel(tops))=[];
        end

        if t_ind(1)== t1(1);
            t_ind(1)=[];
            tops(1)=[];
        end
    end
    %eliminate tights tops
    if length(t_ind)>3
        m=mean(tops);
        for j=1:length(t_ind)
            if tops(j) < 0.25*m
                t_ind(j)=0;
            end
        end
        t_ind=t_ind(t_ind>0);
        tops=p1(t_ind);

    end
    %divide plot the window to two plots
    L1 = floor(length(p1)/2);
    t_ind1 = t_ind( t_ind<=L1 );
    tops1 = p1(t_ind1);
    t_ind2 = t_ind( t_ind>=L1 );
    tops2 = p1(t_ind2);

    figure(1)
    subplot(2,1,1)
    hold off;
    plot(t1(1:L1),p1(1:L1)); hold on;
    plot(t1(t_ind1), tops1, 'ro');
    grid on;
    hold off;

    subplot(2,1,2)
    sec = t1(L1+1:end);
    func = p1(L1+1:end);
    hold off;
    plot(sec, func); hold on;
    plot(t1(t_ind2), tops2, 'ro');

    grid on;
    hold off;
    % asking for acceptance the result.

```

```

reply=input('Satisfied? Y/N [y]: ', 's');
if isempty(reply)
    reply = 'Y';
end
reply = reply(1);
satisfied = reply == 'Y' || reply == 'y';
if satisfied
    % save and continue if the result is accepted by writing y or
    pressing enter..
    %continue to next window with one second overlap
    Index=[Index, t_ind+n1-1];
    n1 = n1 + window - 1*fs;
    n2=n1+window;
else
    % Adjust the parametes and try the detection again for the same
    window.
    notok = true;
    while notok
        reply = input(['Minimum amplitude = ' num2str(minAmp) ' New
value?: ', 's']);
        minAmp = str2double(reply);
        notok = isnan(minAmp);
    end

    not_ok = true;
    while not_ok
        reply = input(['Minimum time between 2 tops in sec = ' num2str(A)
' New value?: ', 's']);
        A = str2double(reply);
        not_ok = isnan(A);
    end
    clf;
end

end
for k=2:length(Index)
    if Index(k) == Index(k-1)
        Index(k-1)=0;
    end
end
Index=Index(Index>0);
clf;
%plot the whole signal with its fasit.
plot((1:length(p))/fs,p); hold on;
plot(Index/fs, p(Index), 'ro');

grid on;
hold off;
%save([kodemappe 'fasit/' a '.mat'], 'Index');
end

```

7.2 Function detection

```
function[t_ind tops] = detection( p1, minAmp, A )
%Detection of the reference.

fs=500;
%Detection of the tops and bottoms.
t_ind = findpeaks(p1);
b_ind = findpeaks(-p1);

% handling numbers of tops and bottoms
if numel(t_ind) ~= numel(b_ind)
    if numel(t_ind) > numel(b_ind)
        s=numel(t_ind)-numel(b_ind);
        for k=0:s-1
            t_ind(numel(t_ind)-k)=[];
        end
    else
        s=numel(b_ind)-numel(t_ind);
        for k=0:s-1
            b_ind(numel(b_ind)-k)=[];
        end
    end
end
end
botvals = p1(b_ind);
%handling the acceptance of minimum amplitude of tops
ampl = p1(t_ind) - botvals;
t_ind=t_ind(ampl > minAmp);
tops = p1(t_ind);
A=A*fs;
[ind,peaks]= nodouble(t_ind,tops,A);
t_ind=ind;
tops=peaks;

end
```

7.3 Function findpeaks

```
function [ind,peaks] = findpeaks(y)
% FINDPEAKS Find peaks in real vector.
% ind = findpeaks(y) finds the indices (ind) which are
% local maxima in the sequence y.
%
% [ind,peaks] = findpeaks(y) returns the value of the peaks at
% these locations, i.e. peaks=y(ind);
%
% Funksjonen ble funnet i Matlab Support av Eli Vatland, våren 1998
%

y = y(:)';

dy = diff(y);

ind = find( ([dy 0]<0) & ([0 dy]>=0) );

%if y(end-1)<y(end)
% ind = [ind length(y)];
%end

if nargin > 1
    peaks = y(ind);
end
```

7.4 Function nodouble

```
function [ind,peaks]= nodouble(ind,peaks,A)

for k=2:numel(ind);
    if ind(k)-ind(k-1)<A;
        if peaks(k)<peaks(k-1);
            peaks(k)=0;
        end
        if peaks(k)>peaks(k-1);
            peaks(k-1)=0;
        end
    end
end
Adx=find(peaks>0);
ind=ind(Adx);
peaks=peaks(Adx);
end
```

7.5 Function comp_detection

```

function [ t_index ] = comp_detection( channel )
%compression detection system for a given channel.
% channel is the given channel the detection system will use
% The function returns t_index: time of the every detected sompression

% The general reprocessing of the signal by removing the artifact of down
% sampling
pressure=channel;
minAmp = 0.3;
A=0.3;
pressure(1:20)=ones(1,20)*pressure(20);
L=length(pressure);
pressure(L-20:L)=ones(1,21)*pressure(L-21);

fs=500;
%Pass band filter the pressure
nn=4;
f1=0.5;
f2=30;
Wn=[f1/(fs/2) f2/(fs/2)];
nmf=fs/2;
[b1,a1]=butter(nn,Wn);
p=[pressure(1)*ones(1,nmf) pressure];
p=filtfilt(b1,a1,p);
p=p(nmf+1:end);
channel=p;
%%
fs=500;
t_ind = findpeaks(channel);
b_ind = findpeaks(-channel);
% handling numbers of tops and bottoms
if numel(t_ind) ~= numel(b_ind)
    if numel(t_ind) > numel(b_ind)
        s=numel(t_ind)-numel(b_ind);
        for k=0:s-1
            t_ind(numel(t_ind)-k)=[];
        end
    else
        s=numel(b_ind)-numel(t_ind);
        for k=0:s-1
            b_ind(numel(b_ind)-k)=[];
        end
    end
end
botvals = channel(b_ind);
%handling the acceptance of minimum amplitude of tops
ampl = channel(t_ind) - botvals;
t_ind=t_ind(ampl > minAmp);
tops = channel(t_ind);
A=A*fs;
%handling the tight tops.
idx=[];
peaks=tops;
ind=t_ind;
for q=2:numel(ind);
    if ind(q)-ind(q-1)<A;
        if peaks(q)<peaks(q-1);

```

```
        idx=[idx q];
    end
    if peaks(q)>peaks(q-1);
        idx=[idx q-1];
    end
end
end
idx1=[];
for u=2:numel(idx)
    if idx(u)==idx(u-1);
        idx1=[idx1 u];
    end
end
idx(idx1)=[];
ind(idx)=[];
peaks(idx)=[];
t_index=ind;
tops=peaks;

%handling one top without sequense
if numel(t_index)>3
    for r=2:length(t_index)-1
        if t_index(r+1)-t_index(r)>1*fs && t_index(r)-t_index(r-1)>1*fs;
            tops(r)=0;
        end
    end
end
Adx=find(abs(tops)>0);
t_index=t_index(Adx);
tops=tops(Adx);

%handling the first top
if t_index(2)-t_index(1)>1*fs
    t_index(1)=[];
    tops(1)=[];
end
% %handling last top in the sequense
if t_index(numel(t_index)) >= length(pressure)-fs/2;
    t_index(numel(t_index))=[];
    tops(numel(t_index))=[];
end
end
```

7.6 Detection and evaluation script

```

%this script is done to run the compression detection system and evaluate
%the prformance.
%The user can choose the channel the detection system will be based on.
clear all; close all; clc;
kodemappe
=('E:/masterThesis/Akuttmedisinisk_signalbehandling/Hjertekompresjon/');
datafiler= ('E:/masterThesis/Akuttmedisinisk_signalbehandling/data/');
load([datafiler 'longhw']);
fasitDet=cell(40,1);
autoDet=cell(40,1);
for k=2:length(fasitDet)+1
    a=arecs(k);
    a=a{1,1};
    B=load([kodemappe 'fasit/' a '.mat']);
    fasitDet{k,1} = B.Index;
    load([datafiler a '.mat']);
    fs=500;
    % choose the channel that the detection system will be based on by
    % uncomment the choosed channel
    %pressure=SIGNALS.thorax_imp.';
    %pressure=SIGNALS.ecg_diff.';
    pressure=SIGNALS.pad_pressure.';
    %call the compression detection system.
    [t_index]=comp_detection(pressure);
    %compute the result in a cell array.
    autoDet{k,1} =t_index;
end

%%
% The evaluation is considered in this section.
%Prob_falsk is the probability of false detection for every threshold
%value.
%Prob_correct is the probability of correct detection for every threshold
%value.
Prob_falsk=[];
Prob_correct=[];
for thr=0:20:80 %The threshold values.
    %P_falsk is the probability of false detection for every procedure for
    %a specific threshold value
    %P_correct is the probability of correct detection for every procedure
    %for a specific threshold value
    P_falsk=[];
    P_correct=[];

    for s=2:length(autoDet)
        F=fasitDet{s,1};
        A=autoDet{s,1};
        Nd=[]; % correct detection
        Nf=[]; % false detection
        Nm=[]; % missed detection
        idx=[];
        idx1=[];
        if ~isempty(F) && ~isempty(A)
            for i=1:length(F)
                for j=1:length(A)
                    if abs((F(i)-A(j))) <= thr;
                        idx=[idx i];
                        idx1=[idx1 j];
                    end
                end
            end
        end
    end
end

```

```
end
end
end
end
Nd=F(idx);
F1=F;
F1(idx)=0;
Nm=F1(F1>0);
A1=A;
A1(idx1)=0;
Nf=A1(A1>0);
% Pf is the probability of false detection for a specific procedure
% and specific threshold value
% Pd is the probability of correct detection for a specific
% procedure and specific threshold value
Pf=length(Nf)/(length(Nf)+length(Nd));
Pd=length(Nd)/(length(Nm)+length(Nd));

P_falsk=[P_falsk Pf];
P_correct=[P_correct Pd];
end
mean_falsk=mean(P_falsk);
mean_correct=mean(P_correct);
Prob_falsk=[Prob_falsk mean_falsk];
Prob_correct=[Prob_correct mean_correct];
end
%%
% plot the diagrams.
x=0:25:100;
figure(1); bar(x,Prob_falsk,0.5);
set(gca,'YLim',[0 1]); grid on;
xlabel('Threshold value');
ylabel('Pf');
title('The probability of false detection');

figure(2); bar(x,Prob_correct,0.5);
set(gca,'YLim',[0 1]); grid on;
xlabel('Threshold value');
ylabel('Pd');
title('The probability of correct detection');
```


7.7 Label of the heart rhythm on ECG signal

```
%a script to show the label. these labels are the the heart rhythm
%and placed where the rhythm starts in an ECG signal
clc;
clear all;
datafiler= ('E:/masterThesis/Akuttmedisinisk_signalbehandling/data/');
load([datafiler 'longhw']);
A=2; %patient number
a=arecs(A);
a=a{1,1};
load([datafiler a '.mat']);
annotering=epout.EPI{1,A};
%annotering=annotering{1,1};
Index=epout.SMP{1,A};
%Index=Index{1,1};

fs=500;
EKG=SIGNALS.ecg_diff.';
s_avvik=std(EKG);
y=[-5*s_avvik 5*s_avvik];
plot(EKG);
set(gca, 'ylim', y);
for i=1:length(annotering)
    x1=Index(i,1);
    y1=-4*s_avvik;
    if strcmpi(annotering(i,1), 'C',1) == true
        text(x1, y1, ['\rightarrow' annotering(i,1)], 'HorizontalAlignment',
'left', 'color', 'r');
    else
        text(x1, y1, ['\rightarrow' annotering(i,1)], 'HorizontalAlignment',
'left');
    end
end
end
```

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