Portable device for algorithmic analysis and feedback according to the stress level of humans

Master Thesis

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Portable Device for Algorithmic Analysis and Feedback according to the Stress Level of Humans

Master Thesis

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Abstract

A high stress level over a long time affects the health and causes a decrement of the quality of live as stress symptoms are often not noticed or neglected. Therefore it would be important to feed back human stress level parameters, e.g. the heart rate variability (HRV), directly to the stressed person. The aim of this Master Thesis is to present a portable device measuring the HRV and give the feedback directly to the person wearing this device. Immediate knowledge about the stress level allows to locate momentary stress sources and to cope with it. Being able to analyse stress directly from the HRV allows also to relate it to other measurements taken close to that point in time which make this feedback useful in human medicine e.g. to prevent heart attacks. A first programme code for such a device was already available at the beginning of the thesis. It then was improved and made compatible to show the heart beats from the Electrocardiogram (ECG). To achieve this the beat interval was cleaned up and then interpolated. Moreover the frequency energy was calculated with wavelet frequency analysis. The gathered values of the energies in the LF and HF HRV frequency bands were then visualised with the HrvStressMon application. Also an ECG recorder and according software for visualising and analysing the ECG signal were developed. Interaction with the ECG is now robust as well as the detection of the beats is now initialised properly. With the moving median filter for cleaning up the detected beat intervals and the generic wavelet decomposition tree it is now rather easy to do online processing of the ECG signal to retrieve information about the HRV frequency spectrum.

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  - collaboration
  - providing location and effort for recording ECG data and counting leukocytes
- Larisa Fritzsche
  - verification of similarity of automatic and manual ectopic beat removal
- Alexey Morozov
  - code for viewing ECG data
  - code for detecting ECG beats
  - code to perform wave-let analysis
  - explanations how wave-let analysis works
- Barbora Blaha
  - prototype code for communicating with the ECG device
  - coefficients for the wave-let Analysis
  - prototype code for working with wave-let analysis

Contents

Chapter 1

Introduction

A lot of jobs are getting more and more demanding these days, asking a lot from employees and managers and making them frustrated and rising their stress level. It can be considered common sense that a high stress level over a long period is not healthy and for sure affects the quality of life. Burnout, depressions or a weak immune system can be the consequences of it. Also the health of the heart can suffer and reveal this by deviation from a normal beat pattern. To keep damage low one should be aware of this stress and cope with it properly.

The goal is now to develop a wearable device that supports measuring stress parameters of humans and allows to give feedback about the stress state.

In general, to get a rather objective measurement of ones own stress state it is required to visit a doctor. Maybe the reported symptoms or different measurements like cortisol level, heart rate, blood pressure and blood analysis reveal a high level of stress.

However this measurements are rather punctual and therefore can not point promptly and directly to the stress root causes. Also some methods are invasive and, as consequence cannot be done with a high frequency.

With the program developed in this thesis it is possible to calculate generically the energies of certain frequency bands of the heart rate variability (HRV) and give prompt feedback about it. This is done with a newer version of QBIC [1]. Besides already existing automatic beat detection also automatic removal of ectopic beats is implemented to receive a clean signal.

This project serves as basis for relating the rather well known stress measures from the heart rate variability with other medical data of a patient. This should later allow to really have an even more wide range of possibilities to find out if a person is suffering from mental stress.

In the following chapters first an insight is given into the overall ideas and the associated terms. Then the proposed solution is presented where design choices and verification of proper functionality of the important parts are explained and assessed. After the research contribution and the conclusion of the thesis the appendix contains the operating instructions of the applications.

Chapter 2

Background

In this chapter the fundamental terms and methods relevant for the thesis are explained.

2.1 Glossary

Alphabetically sorted list of used acronyms and terms.

Arrhythmia Irregular heart beat rhythm; caused by either stress of young people or usually with elderly people having heart problems

ECG Electrocardiogram

Ectopic beat Heart beat that is not in the regular rhythm; arrhythmia and extra-systoles and other irregular beats and resulting beat intervals

Extra-systole (ES) Extraneous heart beat; not regular heart beat and usually completely out of the regular rhythm; causes either a following compensational break or shifts the heart beat

HRV Heart Rate Variability; the heart doesn't always beat with exactly the same speed making it varying

2.2 Stress detection

Stress can be detected in various ways. Either the person realises by itself that the stress level is high or it is indicated by an external measurement. In both cases something should be done to cope with it. The former requires a minimal self-awareness and the person has to think about the own stress level at least a few times a day. This measure is subjective and depends heavily on the self perception. The latter of course requires additional equipment to acquire the data.

A wide range of measurements can be performed on the human body where the gathered data contains information about the stress level. There are some more well known and researched measures like the salivary cortisol hormone level, blood pressure, the heart rate as well as the heart rate variability. Also blood values, namely the number and type and age of white blood cells, and urine can be used to make conclusions about stress. But at least the former of these is not yet that well known for it.

2.3 Bio-Feedback

The idea behind bio-feedback is to provide the human directly with information about the current state of his body. Thus enhancing consciousness and enabling to react specifically on certain events or states. One reaction can be to mentally influence the state of the body just by thoughts and bring it into a better or healthier state.

2.4 Existing solutions

There are products that can measure in some way the stress by measuring and analysing the pulse taken from a finger on each hand. They then display the level of stress on an LED scale. Conventional methods just record the ECG signal and do the analysis afterwards.

Due to the fact that the topic of nearly realtime feedback of HRV values is rather new no similar research work is known with which the project could be compared.

Chapter 3

Proposed Solution

3.1 ECG signal acquisition

With the provided ECG device that can be connected to the RS232 serial connection the ECG signal is received at a rate of 500 Hz completely satisfying the guidelines in [2]. When connected to a simulator or to a human it returns the expected data provided the electrodes were properly attached.

The already existing code to control the ECG device was very useful but it was still necessary to do some adjustments making it reliably initialise the device every time.

3.2 Heart beat detection

The signal is passed through a detection algorithm that locates the heart beats in the signal. The detection on a signal from an ECG simulator returned beats in intervals just as expected.

It was possible to use the beat detection implementation provided by Alexey Morozov. As the results from the simulator and other recorded signals were almost perfect it can be relied on the quality of the provided software.

3.3 Beat interval cleanup

For calculation of the HRV energy it is required to have a clean signal. If it is not already the case after the recording and detection this has to be ensured before the analysis is performed. The guidelines for measuring heart rate variability [2] suggest that ectopic beats, arrhythmic events, missing data and noise effects should be removed prior to calculating power spectral density (PSD) values.

Modifying the ECG signal directly is not trivial and might lead to irritation of the beat detection algorithm. Removing parts from the signal will destroy frequency information. If we want only in one place to really deal with removing ectopic beats and interpolating such generated gaps or already existing gaps of lacking signal, it seemed best to do this on the level of beat intervals (RR distances between two a QRS heart beat complexes).

Ectopic beats can be considered as statistic outliers. To detect these and still allow gradual overall change (heart rate going up or down because of more or less activity) a windowed median filter with a window size of the 20 last beats was implemented and applied. A beat was then only accepted as a normal if it did not deviate more than 30% from this moving median. As a positive side-effect also periods where no heart beat was detected are removed and the average of the following correct beat interval is assumed for this time. It is not yet possible to distinguish between beats that are removed because of too bad or no signal and real heart beats that are removed because they are ectopic. Moreover a beat could be also a misinterpretation of the ECG signal by the beat detector and therefore might be removed. However all this information might be required to decide which intervals should be considered as regular intervals and used for the statistics calculation and which should be ignored because they are ectopic.

A moving average filter would have been possible as well but it is easily influenced by outlier values, which still need to be passed through it to let the filter follow also gradual change or at some point even to recover after abrupt change. The median remains stable if there are only few such values.

Table 3.1: Comparison of automatic and manual beat removal

Parameters	ADAR method	MDMRAR method	p-Value
# NN	408.18 ± 73.87	407.08 ± 73.64	0.99
# accepted NN	395.64 ± 74.78	395.03 ± 73.35	0.99
Mean NN	0.75 ± 0.13	0.75 ± 0.13	0.99
HR	82.73 ± 17.29	82.65 ± 17.35	0.99
VarNN	0.003 ± 0.004	0.003 ± 0.005	1
SDMM	0.047 ± 0.03	0.047 ± 0.03	0.99
RMSSD	0.041 ± 0.04	0.041 ± 0.05	1
NN50	21.0 ± 32.31	19.66 ± 32.32	0.99
pNN50	6.03 ± 9.63	5.66 ± 9.55	0.04*
MeanDiff	0.000076 ± 0.0004	0.000052 ± 0.0004	0.99
SDSD	0.04 ± 0.04	0.04 ± 0.05	0.99
MinNN	0.58 ± 0.15	0.60 ± 0.15	0.99
MaxNN	0.91 ± 0.16	0.92 ± 0.18	0.99
Modus (Mo)	0.75 ± 0.14	0.74 ± 0.14	1
AMo	54.20 ± 33.48	54.22 ± 33.55	0.99
HRV Ind	9.86 ± 5.23	9.90 ± 5.48	0.99
IN	68.63 ± 70.27	66.38 ± 68.81	0.99
LF	916.63 ± 1802.41	1069.21 ± 2729.94	0.99
HF	435.58 ± 713.32	540.12 ± 1299.3	0.99
HF/LF	0.87 ± 1.29	0.86 ± 1.43	0.99

* The difference is statistically significant

To verify if this filtering was working properly and behaves reasonably like manual editing several statistical values of the beat intervals and also the power in the two HRV frequency bands (LF and HF) were compared. The automatic detection of heart beats with automatic removal of beats with the described moving median filter (ADAR method, automatic detection with automatic removal) was tested to be comparable with the partial manually corrected data (MDMRAR method, manual/automatic detection with manual and automatic removal). From Table 3.1 can be learned that all values except the pNN50 accept the null hypothesis. pNN50 is calculated as NN50/(total number of all NN intervals) and therefore cumulates changes in NN50 as well as # NN and might because of that be quite sensitive and not correlated. As both NN50 and # NN accept the null hypothesis we can nevertheless conclude that both methods are reasonably equal.

First the χ^2 (chi-square) test and the Kolmogorov-Smirnov test were applied to all the HRV variables. Thus, it was determined if the variables could be adequately modelled by a normal distribution. The chi-square test divides the range of each variable into non-overlapping intervals and compares the number of observations in each class to the number expected based on the fitted distribution. The Kolmogorov-Smirnov test computes the maximal distance between the cumulative distribution of each variable and the cumulative distribution of the fitted normal distribution. When the lowest p-value of the test performed greater or equals to 0.05, the idea can not be rejected that the variable comes from a normal distribution with 95% or higher confidence. For variables that either do not come from a normal distribution or are not big enough to apply the chi-square test parametric analysis can not be applied to compare them. Therefore non-parametric analysis which is less sensitive to the presence of outliers but is somewhat less powerful than the parametric t-test was used.

As a second step to compare two paired variables the validated non-parametric paired Wilcoxon test was used with the null hypothesis (H_0): mean = 0.0 and the alternative hypothesis (H_A): not equal. If the p-value was > 0.05 the null hypothesis was not rejected with $\alpha = 0.05$. If the p-value was < 0.05 the null hypothesis was rejected with $\alpha = 0.05$.

Figure 3.1: Normal regular beats

As a reference how the filter is behaving in specific cases some samples are provided here. Figure 3.1 shows a good recording with a regular beat pattern. Figure 3.3 shows various cases of successful beat detections. In (a) an extra-

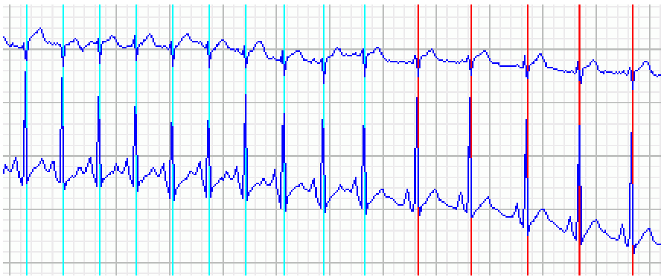


Figure 3.2: Completely normal beats removed

systole and the according compensatory break were successfully detected by the algorithm and sections with no signal are successfully treated as in (b). (c) demonstrates an unconfirmed removal of an extra-systol and its compensatory break where in (d) probably also found an extra-systole was found but without compensatory break.

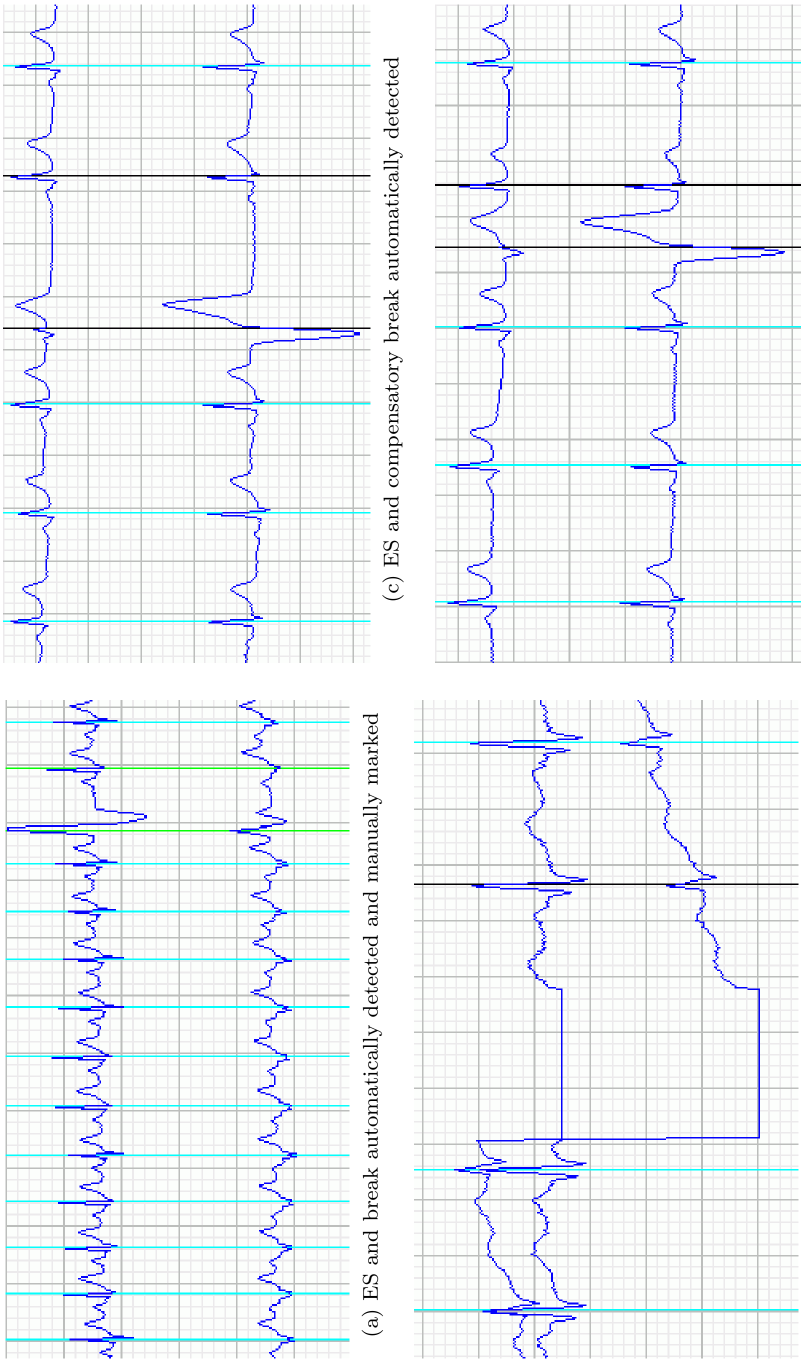
However there are still some flaws in the algorithm as Figure 3.4 demonstrates. An extra-systol was successfully detected in (a) but not its corresponding compensatory break. Possible extra-systols or maybe only arrhythmia is removed in (b) and probably should have been kept. According to the supervising doctor arrhythmia should still go into the analysis as in (c) but the guidelines for HRV [2] tell that it should be removed. Because of a quite high heart rate it seems that the extra-systole in (d) and the break are not sufficiently deviating from the median and therefore are still accepted. Also from the eye they seem not so remarkable shifted from the regular distance.

Also cases where the heart seems to relax completely and really slow down its rate quite a lot are unfortunately not captured as demonstrated in Figure 3.2.

The manual correction of the data and statistical comparison with the fully automatic processing suggest that it works very well. The naked numbers of the automatic and manual beat removal in Table 3.2 are rather unexpected but can be explained. Many beats were automatically removed because they tended to be quite arrhythmic and also while manually marking the beats the possibly wrong intention was around that arrhythmia should still be present in the analysed signal.

Table 3.2: Count of the different marked beats

Auto remove	67
Auto remove + not remove	207
Auto remove + remove	189
Manual not remove	8
Manual remove	249
Normal beats	17079
Beat types not in a category above	0
Total number of beats analysed	17799



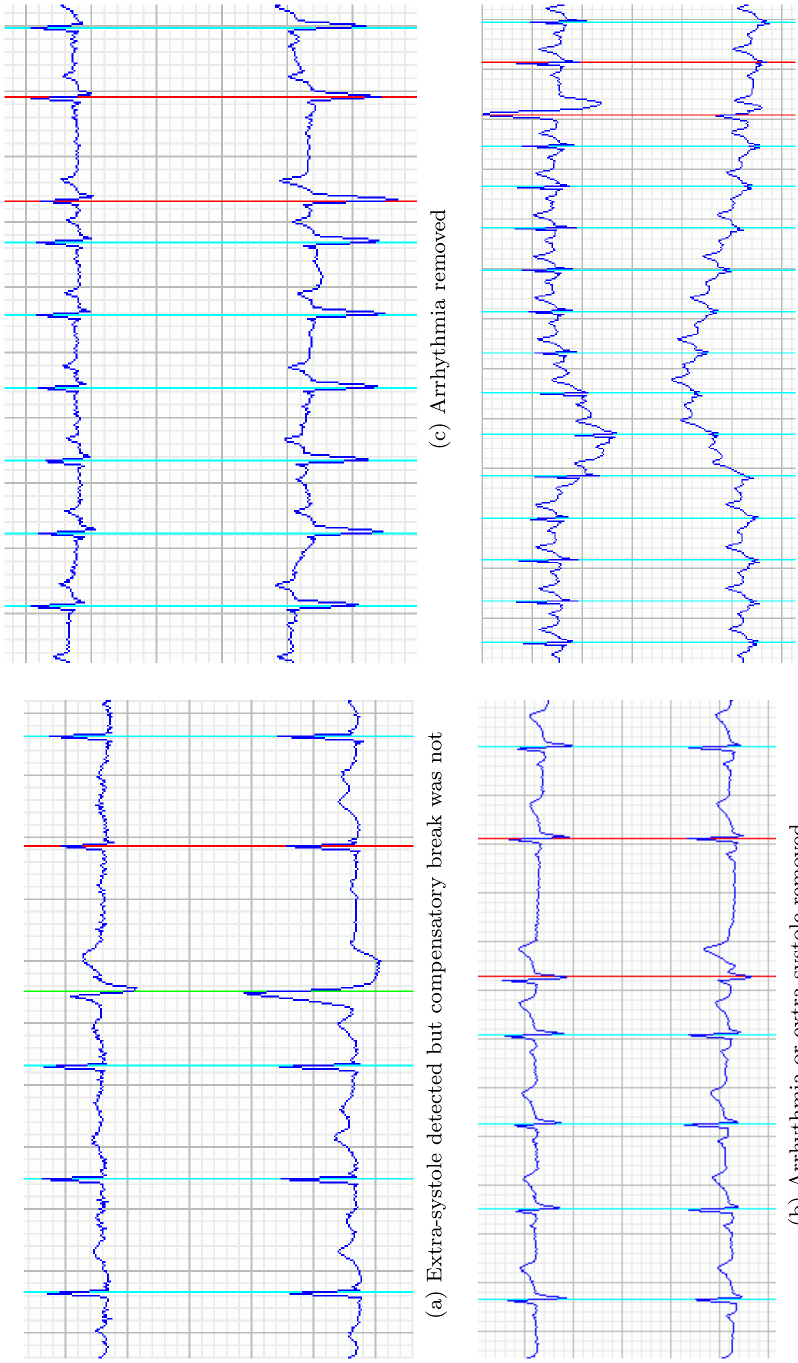
(a) ES and break automatically detected and manually marked

(b) One beat is skipped because of missing signal

(c) ES and compensatory break automatically detected

(d) Probably extra-systole with no compensatory break

Figure 3.3: Successful detections of ectopic beats



(a) Extra-systole detected but compensatory break was not

(b) Arrhythmia or extra-systole removed

(c) Arrhythmia removed

(d) Extra-systole and compensatory break not detected

Figure 3.4: Partially or completely wrong detections

3.4 Beat interval interpolation

Before the information of the detected beat intervals can be passed on to the wave-let analysis it needs to be converted into a curve with constant sampling rate. The beats are plotted according to their point in time on the abscissa and the distance to the previous beat on the ordinate as in Figure 3.5 together with the interpolation. They are inherently not equally spaced on the abscissa. For better verification of the proper interpolation, which is done with 10 Hz, a smaller section is shown (Figure 3.5b).

3.5 HRV energy calculation

3.5.1 Frequency analysis methods

A wave-let frequency analysis can split the frequency as shown in Figure 3.6. The sampling frequency (Fs) of the input signal is reduced to its half, because of the Nyquist theorem and then split into a lower ($0 - Fs/4$) and upper ($Fs/4 - Fs/2$) frequency range.

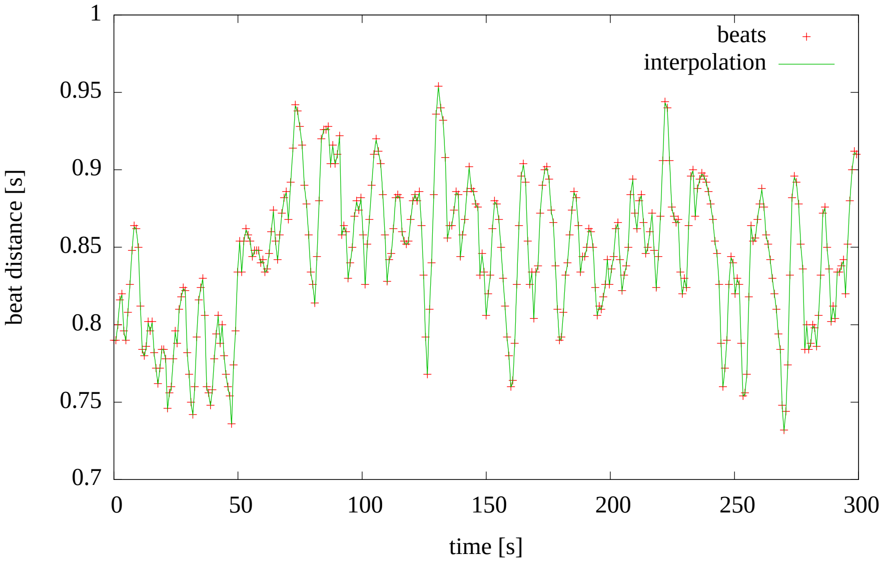
A property of the wave-let analysis influences the way of how the upper frequency range of each analysis split step behaves. The frequency range gets mirrored which is denoted by "m" on the respective edge. This affects the further analysis and is, just like multiplying a number repeatedly by -1, reverted by an other mirroring.

In theory the wave-let analysis gives the same results as an FFT transformation. Therefore the total energy returned by both methods should be the same as well as the power measured in the frequency sub-bands.

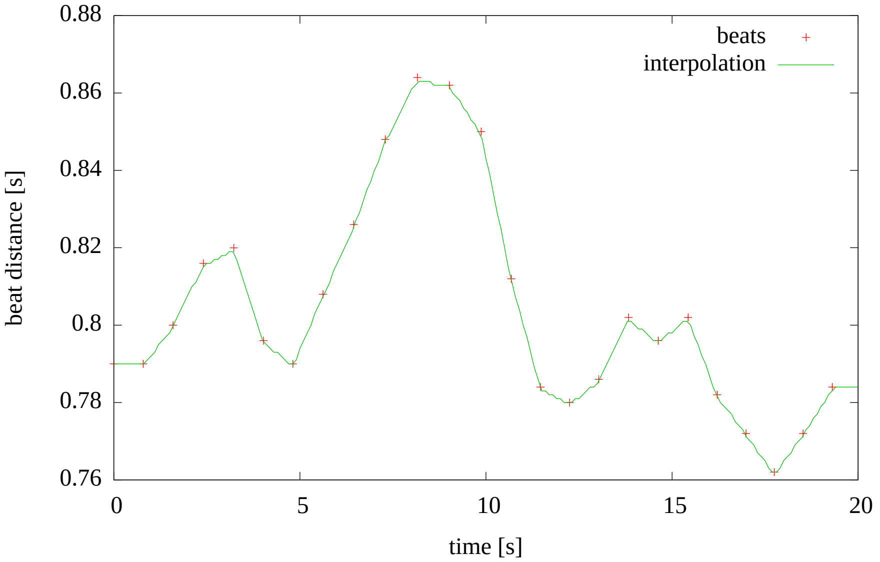
In practice the results are not completely congruent but the deviation is inherently induced by the way both algorithms analyse the data. FFT does it for a given set of data points and gives the information for each frequency that is detectable, given this number of sampling points and the time span they represent. Using only at a smaller time span FFT would give the information about this smaller time span. As fewer points are used this is less precise and also the captured frequency range is smaller. Considering this fact, it is not possible to really find out how the power of a certain frequency range changes over time.

Wave-lets are completely different. They only need a limited number of data points (related to the depth of the split tree) to find out the power of a frequency range. On the other hand they can not rely on so many data points for this power at this point in time so the precision there is not so high. But FFT would not be better with this few points either.

Both methods obviously need some data before a result can be computed. In case of FFT it is best to do this with as much data as possible to get the best possible accuracy and detect also lower frequencies. The number of samples used, given a specific sampling rate, defines the minimal frequency that can be detected. Of course the sampling rate also limits the maximal frequency that



(a) Complete recording



(b) Only part of the recording

Figure 3.5: Beats with interpolation

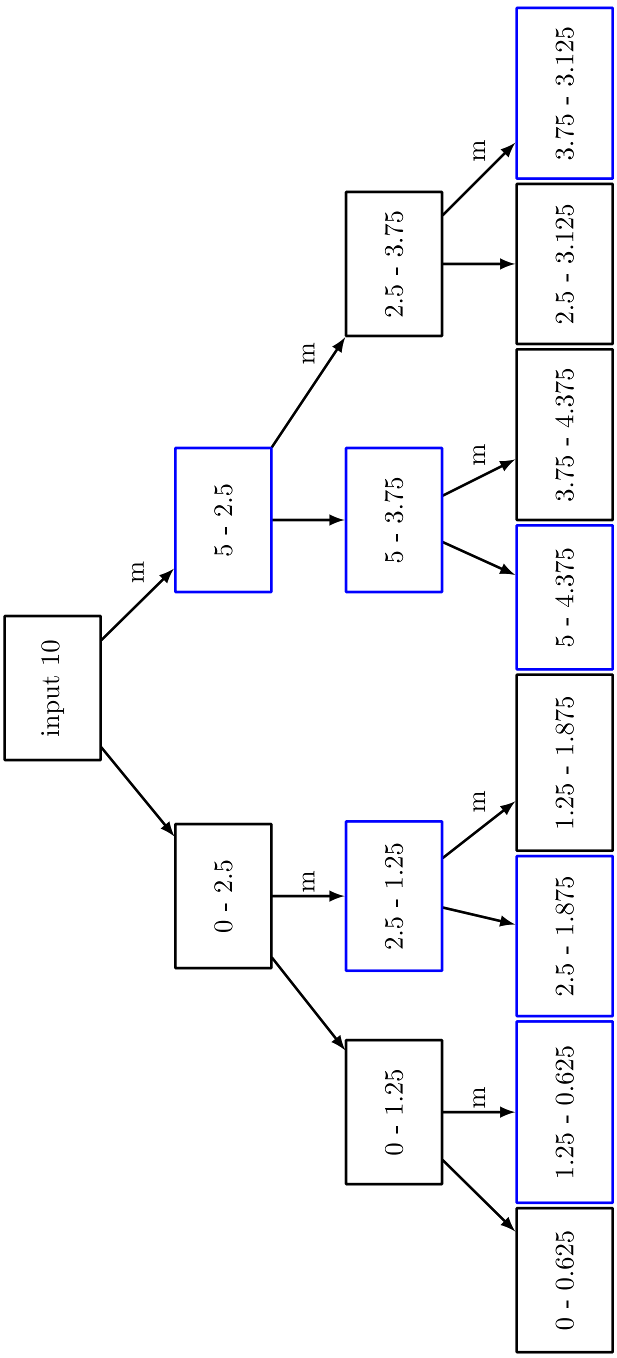


Figure 3.6: Wave-let frequency split tree (numbers are frequencies e.g. Hz)

Table 3.3: Comparison of FFT and wave-let analysis

Item	LF			HF			q		
	FFT	Wave-let	Deviation	FFT	Wave-let	Deviation	FFT	Wave-let	Deviation
20090716-1026	871.185	836.559	-3.975 %	115.713	115.077	-0.550 %	7.529	7.270	-3.443 %
20090722-0952	3190.997	3388.106	+6.177 %	5409.197	4828.864	-10.729 %	0.590	0.702	+18.937 %
20090723-1030	292.865	283.252	-3.282 %	84.624	80.297	-5.113 %	3.461	3.528	+1.929 %
20090728-0910	1390.980	1348.060	-3.086 %	419.787	357.048	-14.945 %	3.314	3.776	+13.944 %
20090728-0943	160.065	214.394	+33.942 %	700.524	1358.098	+93.869 %	0.228	0.158	-30.911 %
20090728-0954	254.918	207.162	-18.734 %	109.724	113.006	+2.991 %	2.323	1.833	-21.094 %
20090728-1006	904.032	767.665	-15.084 %	111.246	127.082	+14.235 %	8.126	6.041	-25.666 %
20090728-1048	136.139	158.710	+16.579 %	75.064	72.701	-3.147 %	1.814	2.183	+20.367 %
20090729-1038	696.908	803.224	+15.255 %	1194.359	1396.157	+16.896 %	0.583	0.575	-1.403 %
20090731-0909	57.453	55.577	-3.266 %	147.156	142.781	-2.973 %	0.390	0.389	-0.301 %
20090731-0922	134.738	176.936	+31.318 %	160.422	131.731	-17.885 %	0.840	1.343	+59.919 %
20090731-1343	356.313	327.311	-8.139 %	5.429	10.913	+100.997 %	65.627	29.993	-54.298 %
20090811-0850	10.825	12.010	+10.948 %	18.459	20.238	+9.633 %	0.586	0.593	+1.199 %
20090818-0848	811.406	681.227	-16.044 %	310.571	215.259	-30.689 %	2.613	3.165	+21.130 %
20090819-0859	2197.011	2824.364	+28.555 %	634.850	540.516	-14.859 %	3.461	5.225	+50.991 %
20091022-0832	171.440	117.736	-31.325 %	35.810	39.847	+11.272 %	4.787	2.955	-38.282 %
20091120-1004	3923.442	2568.658	-34.531 %	4365.095	637.557	-85.394 %	0.899	4.029	+348.243 %
20091123-0910	54.854	20.765	-62.145 %	124.561	68.401	-45.087 %	0.440	0.304	-31.064 %

can be detected. For wave-lets it is similar. More samples make it more reliable and better comparable to FFT rather because of averaging of the results than because of a wider support for each calculated energy point. The minimal number of samples required to get a result depends on the input sampling frequency and the required precision of the frequency band borders. From this the maximal required wave-let decomposition tree depth is deduced for each frequency band. Only half of the samples reach the next deeper level. By backwards calculation it is possible to find out how many samples are needed and thus how long it takes before a result is available.

In the big picture FFT is looking at the whole set of data points and returns more precise results concerning the power of frequency bands. Wave-lets cannot look at this many points at the same time, but they just look at a reduced set, building up the view of the whole set gradually, outputting data about the considered data points but not knowing about future or unprocessed ones. This is of course less precise than FFT for the whole analysis but quite useful for getting a momentary picture of the power in the frequency bands. Also wave-let analysis can be performed on a stream of data and only in the order of number of filter coefficients samples have to be store per tree node.

3.5.2 Used method to calculate the required HRV energies

The required HRV energies of the LF (0.04 - 0.15 Hz) band and HF (0.15 - 0.4 Hz) band were computed through wave-let analysis as they should be able to return more or less reliable values as soon as possible. FFT would need at least 1/0.04 s = 25 s of data to be able to calculate some energy for the LF band. More seconds of data would be better. Moreover the computation is not as efficient as with wave-lets.

The signal is fed with a 10 Hz sampling rate into the wave-let analysis and every 128 samples or 12.8 seconds new values for LF and HF are calculated. The used tree depth is 7 because the frequency band boundaries are reached then closer than 0.01. At this depth because of the down-sampling by factor two at ever tree level 128 samples are needed to get at least one at the lowest level. As wave-let filter the orthogonal Daubechies with 8 coefficients, named Daubechies 4 (db4) in MATLAB, is used. Its analysis results on sample heart beat data are closest to those calculated with FFT. The more the shape of the wave-let resembles the shape of the signal on different scales the better the result.

Table 3.3 lists a comparison of FFT with wave-let analysis values for LF, HF and their ratio q. For most of the LF and HF values the difference between wave-let and FFT is less than 20% which is quite good for only 5 minute ECG data corresponding to 3000 samples.

It was possible to get a first idea how to work with the code but building up the decomposition tree would have to be done completely manually. To prevent manual errors and offer fast change of the analysed frequency bands a generic tree generation algorithm was implemented. This allows to specify a maximal tree depth and required frequency bound precision for splitting the frequency. To get now the energy of a specific frequency band it is sufficient to specify the frequency fed into the filter, the maximal tree depth, the frequency boundaries and the precision with which these should be reached. Then the samples have to be fed only into the filter and the previously returned handle to the frequency band energy pot has to be queried if a valid value is present after the last reset.

3.6 Feedback of gathered parameters

The gathered values of the energies in the LF and HF HRV frequency bands are visualised with the HrvStressMon application, which makes use of all the previous steps described in this chapter, importing the resulting program libraries and then displaying graphically quite simple the calculated energies for LF and HF when the ECG is properly connected. To make the two measured parameters visible on a graphical display the enhanced representation of a dot in a coordinate system, filled circle, is used. In Chapter 5 more interesting possibilities are suggested.

It can handle two cases of problems automatically. When the ECG can not be contacted over the predefined RS232 serial connection it retries to connect every 10 seconds. And if the ECG reports a leads off or there are no beats detected for 5 seconds the beat detector is reset together with all other analysis filters.

Chapter 4

Contribution

For this thesis an ECG recorder software as well as an ECG analysis software visualising the ECG signal, the detected beats and manual corrections were developed. They were not only used to assess the quality of the automatic removal of ectopic beats by manual analysis and comparison to the ECG signal they were also intended to record, prepare and analyse the ECG signal and the HRV to relate the stress found in the HRV with matching blood images. This helps gather information and verify if mental stress could also be detected by interpreting specific values of the blood image.

Chapter 5

Conclusions

5.1 Conclusions

In this thesis the acquisition and processing of the HRV data was assessed and properly checked to make it really work. Three programs were developed. One to record ECG data, the second to analyse it and a third to really make use of the parts assessed by the other two giving prompt feedback about the HRV stress parameters retrieved almost directly from the connected ECG or ECG similar device.

The automatic treating of the ectopic beats could have been probably solved better. The beat detector should be improved to return not only the beats but also a measure how likely they are normal or not, at least in terms of their shape. Furthermore, with a little more effort the moving median filter could have been extended to be more precise and adjust dynamically the sensitivity according to the natural change in the heart rate.

The comparison of the results from the FFT and wave-let analysis leads to unusual and oddly big differences at first glance between the two. This leaves some remaining doubts about the correctness of the implementation. Maybe there are still some more checks required. However, trusting people who know more about wave-lets, the system is working properly and such big differences to FFT is in the nature of wave-let transformation.

Although it was one of the main motivations of this project to find a relation between HRV parameters characterising stress this failed because it needs really more effort than initially planned.

Altogether the goal of being able to analyse the frequency band energies of the HRV was reached.

5.2 Future Work

As there are still some drawbacks in the filters concerning the ectopic beats, it would be good to come up with enhancements. These could be achieved by cutting to the human pulse limits, improved moving median and an evaluation of the Kalman filter.

Also the initialisation of the beat detection algorithm can still be increased as well as the way how the ECG signal samples are passed to. Some special cases still do cause problems and signal pauses lead sometimes to detection of beats at obvious positions without a peak.

For the feedback of the LF and HF parameters a lot of different methods are possible. Displaying an image more or less bright according to one parameter and moving it around with varying speed according to the other parameter.

To make really use of the bio-feedback approach finding a significant coefficient that characterises mental stress by analysing the HRV would be ideal.

Appendix A

Operation manuals

Simple usage instructions to get started with the applications.

A.1 HRV monitoring software

The actual HRV stress monitor software (HrvStressMon) indicates on the screen with a moving sphere the values of the current energies of LF an HF. The initial position is on the bottom left. As soon as HRV values arrive the sphere starts to move in steps proportional to the energy values. LF values move it along the x- and HF values along the y-axis. If it reaches a border its direction is reversed and it moves back again.

To start the application the ECG should be attached properly with the four electrodes and connected properly to the computer (Normal PC or QBIC). Then the application or the QBIC can be turned on. On the PC the application can be started with `V24.Install~ HrvStressMon.Start~`. Where the first command is required to install the driver for the serial connection to the ECG and the second really starts the application.

Electrodes have to be attached as follows: The electrode of the black plug should be positioned above the right hip bone on the stomach (right leg derivation), the red one is positioned on the palm-side of the right hand wrist or above the right breast (right arm derivation), the yellow one is positioned on the palm-side of the left hand wrist or above the left breast (left arm derivation) and the green one is positioned above the left hip bone on the stomach (left leg derivation).

A.2 ECG recording and analysis software

Usage instructions for the ECG recorder software and the ECG analysis software. They can be started with

```
V24.Install~ WMHRVRecorder.Open~
```

and

```
HRVAnalysis.Open~
```

HRV Recorder v0.1 – Description

GUI elements

Description of the graphical user interface elements from top to bottom.

Top Row

Time of last complete measurement

- Only displays a date and time when there was already a full complete recording for the current patient.

Space used by recordings (GiB)

- Total size of all raw data ECG files. Critical when reaching the originally free disk capacity.

Patient Identification

Family name, First name, Sex, Birthdate

Countdown Area

Displays countdown when recording.

ECG curve display

Displays the leads **I** = LA - RA and **II** = LL - RA.

Button row

- ***Validate***
  - Validate the patient data, if successful then it's possible to start recording.
  - Please check again after pressing if everything you entered is still correct.
- ***Edit***
  - Appears when data was validated. Press to correct the patient data. Will change back to Validation mode.
- ***Start/Stop***
  - Start the ECG recording and if it is started also stop it if there is something wrong.
- ***Update***
  - Appears after a recording for the current patient was made and then Edit was pressed.
  - This updates the information of the patient (if there was something to correct) and stores it.
- ***Init ECG***
  - Only appears if the ECG could not be connected when the application started or if the ECG was not connected properly when ***Reset ECG*** was pressed.
  - Try to connect the ECG.
  - If ECG was not connected initially then also a warning dialog appears.
- ***Reset ECG***
  - Close and reopen the connection to the ECG. Can also help finding problems when ECG is not connected. If this is the case the ***Init ECG*** button appears.
  - Helps checking if the ECG is still plugged properly into the Computer.
- ***Show/Hide ECG***
  - Show or hide the ECG curve display.
- ***New***
  - Press before making a recording for a new patient. Switches to a new empty patient identification form.

System

Reboot/Shutdown: Menu at the bottom left of the screen: *System > Reboot*
Then wait about 30 seconds. The screen turns black and the machine reboots.
To shut down turn the machine off when the screen turns black.

Restart application: Stop: *Develop > Quit HRV Recorder* or *System > Quit HRV Recorder*
Start: *Apps > HRV Recorder*

HRV Analysis v0.5 – Description

GUI elements

Description of the graphical user interface elements from top to bottom.

Patient and recording selection

1. Select the file when the recording was made (recordings are grouped by date).
2. Select the patient at that day (sorted by time of recording).
3. Select the desired recording (if there are multiple).

There are four buttons to nativate through the entries

|<	select the first
<	select the previous
>	select the next
>|	select the last

When there are no next or previous elements available the corresponding buttons are hidden.

Button row

- ***Load***
  - Load the signal and display it in the display area. Also load any saved beat markers.
- ***Analyse***
  - Process the recorded signal. Detect the beats and display the markers in the signal area.
  - Calculate the statistical and HRV analysis values and display them in a new window.
- ***Clear Beats***
  - Remove all markers that mark the position of a heart beat.
  - Keeps all manual markers and marker changes except manual set markers just for beat positions.
- ***Set Beat***
  - Set a position of a beat or change the position of an automatically detected beat.
- ***Begin Cut***
  - Set or change position of a dummy marker. Currently not used for analysis. Could be used to mark the start of several beats to be ignored by the analysis. To be paired then with ***End Cut***.
- ***End Cut***
  - Set or change position of a dummy marker. Currently not used for analysis. Could be used to mark the end of several beats to be ignored by the analysis. To be paired then with ***Begin Cut***.
- ***Remove***
  - Can be selected together with ***Set Beat***, ***Begin Cut*** or ***End Cut*** in order to remove such a marker.
- ***Ext/Arr***
  - Can be used to toggle the status of a beat position marker. Toggles the state if a beat should not be used by the analysis. Manual mark beats to check the automatic detection of beats to skip (e.g. extra systoles or arrhythmic beats). Conflicts with the ***Not Skip*** state which will get removed if present.
- ***Not Skip***
  - Mark beats that should not be removed because they are completely normal. Toggles the state. Conflicts with the ***Ext/Arr*** state which will get removed if present.
- ***Save***
  - Save all markers to the XML description file.

Signal Display Area

Shows the signals (top I, bottom II) and the different kinds of (beat) markers.

- ***Mouse scroll wheel***
  - Scrolls the signal in time (1/8 of the width). With *left Shift* pressed scrolls always a full displayed width.
  - With *left Shift+left Ctrl* scales the signal in time. With *left Ctrl* scales the signal height.
- ***Double click***
  - Near a signal and only this signal is displayed. An other double click (anywhere) shows all signals again.

- ***Left click*** with some marker modifier selected
  - Click some where to add a new marker of the selected type.
  - Click on a marker to change the type, add a marker of a different type or ***Remove*** the marker.
  - Click and hold to move a marker (types: beat, begin cut, end cut).
- ***Right click***
  - Set the start position for the sample number / time difference calculation in the status bar at the bottom.
- ***Home, End, Page Up, Page Down***
  - Scroll *to start*, *to end*, *a page backward*, *a page forward* of the signal.
- ***Marker Colours***
  - *beat*: cyan (cyan)
  - *begin cut*: yellow (yellow)
  - *end cut*: orange (orange)
  - *toggle skip*: magenta (magenta)
  - *automatic skip*: violet (violet)
  - *beat + toggle skip*: red (red)
  - *beat + automatic skip + toggle skip*: green (green)
  - *beat + automatic skip*: black (black)
  - *beat + toggle not skip*: green (green)
  - *beat + automatic skip + toggle not skip*: red (red)
  - *all remaining* and *other combinations*: blue (blue)

Status Bar

Display the cursor start position and the current cursor position. Displays the thereof calculated sample number difference, time difference and the resulting (heart) beats per minute.

System

Handle Application:	Start:	Apps > *HRV Analysis*		
	Stop:	Develop > *Quit HRV Analysis*	or	*System* > *Quit HRV Analysis*

Appendix B

Task Description

Original task description of the master thesis (see following pages).

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Computer Systems Institute
Native Systems Group

Tragbares Gerät zur algorithmischen Bestimmung und Rückmeldung des Stresszustandes von Menschen

Masterarbeit für Philipp Bönhof (pboenhof@student.ethz.ch)

1. Aufgabenstellung

Ausgehend von existierender Soft- und Hardware soll ein tragbarer Prototyp für zeitnahe Rückmeldung des aktuellen Variabilität der Herzfrequenz eines Menschen entwickelt werden. Ziel dieses Projektes ist das Erkennen von psychischem Stress anhand dieser Variabilität. Das Gerät soll wenn möglich auf Basis des QBIC oder andernfalls des „Arztes in der Westentasche" implementiert werden. Dem Träger dieses Geräts soll dabei laufend dessen aktueller Stresszustand rückgemeldet werden.

2. Ziele

1. Entwicklung eines Systems zur Erfassung der EKG-Daten auf PC-Basis.
2. Erweiterung des bestehenden Softwareprototypen zur Berechnung der Herzfrequenzvariabilität sowohl auf PC als auch auf der Basis von QBIC oder des „Arztes in der Westentasche".
3. Auswertung der aufgenommen Daten und Finden einer Korrelation mit Stress (in Kollaboration mit Dr. Fritzsche).
4. Entwicklung eines Rückmeldungmechanismus für den Stresszustand auf Basis von QBIC oder des „Arztes in der Westentasche".

3. Organisatorisches

Besprechen Sie den Fortschritt des Projekts regelmässig mit Ihrem Assistenten. Die Arbeit und das Lösen von Problemen im Zusammenhang mit der Arbeit liegen aber in Ihrer Verantwortung. Liefern Sie nach 1 – 2 Wochen einen groben Zeitplan ab.

Ihr Bericht am Ende der Arbeit kann in Englisch oder Deutsch geschrieben sein und soll mindestens folgendes enthalten:

- Beschreibung des Problems
- Beschreibung und Motivation der Lösung
- Bedienungsanleitung für den Benutzer
- Zusammenfassung und Beurteilung der Arbeit
- Diese Aufgabenstellung

Geben Sie zwei gebundene Exemplare des Berichts sowie ein Exemplar in elektronischer Form (Postscript oder PDF) ab. Ihre Programme (Source Code und Executables) sollen in elektronischer Form abgegeben werden.

Professor: Prof. J. Gutknecht
Assistent: Florian Negele

Zürich, 12. Juni 2009

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