BACHELOR THESIS

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Degree Program Elektronik/Wirtschaft

Development of Heart Rate Variability Analysis System

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Declaration

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Abstract

The Heart Rate Variability (=HRV) is a rediscovered diagnosis tool in medicine.
First it was discovered in China by Wang Shuhe, a Chinese doctor in the 3rd Century.
In modern medicine, particularly in obstetrics, the first documentation of HRV was in the Sixties. Since the end of the Eighties the interest and publications related to the HRV topic increase in the USA, but in Europe the HRV still does not get the attention it deserves.

This bachelor thesis deals with the development of a Heart Rate Variability analysis system.
This system is implemented in the Open Source Framework "AsTeRICS".
For the HRV data acquisition the True-Sense Exploration Kit by OP Innovations is used.
In this thesis two plugins for the "AsTeRICS" Framework have been developed.
The first one is for the data acquisition of the True-Sense Exploration Kit. This is necessary to get the raw electrocardiogram signal. The second plugin calculates the specific HRV parameters from the raw electrocardiogram signal.

Keywords: Heart Rate Variability, HRV, AsTeRICS, TrueSense, OP Innovations

Kurzfassung

Die Herzratenvariabilität (=HRV) ist ein wiederentdecktes Diagnosewerkzeug in der modernen Medizin. Als erster wurde sie in von dem chinesischen Arzt Wang Shuhe in China im 3. Jahrhundert entdeckt. Die ersten schriftlichen Dokumentationen über die Herzratenvariabilität folgten in den sechziger Jahren, hauptsächlich in der Obstetrik. Seitdem steigt das Interesse und die Publikationen in der USA, in Europa jedoch bekommt die HRV noch immer nicht die Beachtung die sie verdient.

Diese Bachelor Arbeit befasst sich mit der Entwicklung von einem Herzratenvariabilität-Analyse-Systems. Dieses System wird in dem Open Source Framework “AsTeRICS” implementiert.
Für die Datenerfassung wird das True-Sense Exploration Kit von OP Innovations verwendet. Für ein funktionierendes System müssen zwei Plug-Ins für den AsTeRICS Framework entwickelt werden: Das erste dient zur Datenerfassung von dem True-Sense Exploration Kit, dies wird benötigt für das rohe Elektrokardiogramm Signal. Das Zweite Plug-In berechnet von diesen rohen Elektrokardiogramm Signal die spezifischen HRV Parameter.

Schlagwörter: Herzratenvaribilität, HRV, AsTeRICS, TrueSense, OP Innovations

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1 Definition of task

The task is to develop a Heart Rate Variability analysis system in the “AsTeRICS” environment. This analysis system should recognize relliably the signal of any Heart Rate Sensor. Therefore the algorithm must recognize different heights of signal level, dependent on the used Heart Rate Sensor. In this case the algorithm is tested with the True-Sense Sensor. The HRV analysis system should calculate some basic HRV parameters which are necessary for basic diagnoses. This includes the parameters SDNN, RMSSD, SDSD, PNN50 and PNN20. An output port for the DRRI (=Difference of actual RR-Interval to previews RR-Interval) for further expansions should be also implemented.

Additionally the True-Sense Sensor is also not implemented in AsTeRICS, therefore an algorithm for interpretation of the incoming measurement samples must be developed first.

2 Theoretical principles

For a better understanding of the thesis, general information about the HRV, AsTeRICS and the True-Sense Sensor are listed below.

2.1 Heart Rate Variability (HRV)

The Heart Rate Variability (=HRV) describes the ability of the heart to change the timing between one heartbeat to the next heartbeat.
The heart can adapt quickly to constantly changing deviances.
From this it’s following that the HRV is an option to measure the general adaptability of the organism to inner and outer burdens. [1]

The blood cycle is a periodic process, which is initiated from the cyclical work of the heart. In Figure 1, a QRS complex is shown; it describes the different states of a heartbeat. The base value for the calculations of many HRV parameters is the RR-Interval. This is the duration of one R-wave peak to the next R-wave peak. The HRV parameters are necessary to make diagnoses about the health state of a patient.

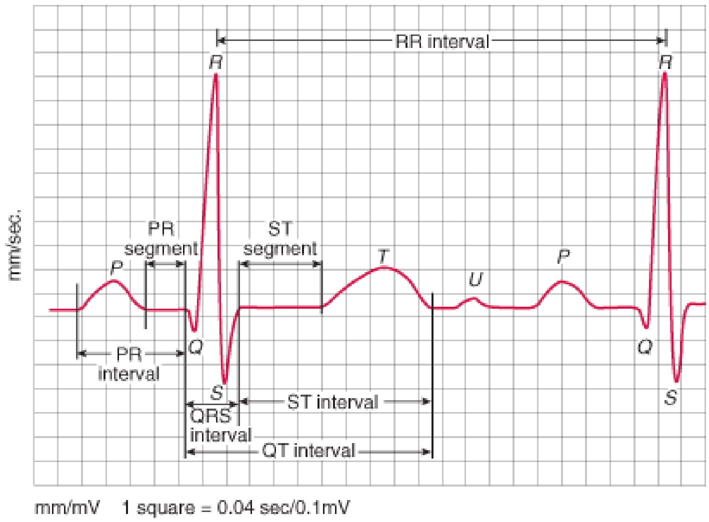

Figure 1: QRS Complex [2]

If the heart frequency stays the same from cycle to cycle like the ticking of a clock, this would be a bad sign. Usually a healthy heart changes the duration of the RR-Interval depending on the inner state and outer situation.
The variability will get less within diseases and the aging process.

For interpreting the variability, a normal heart frequency trend is sufficient. The next picture shows four different heart rate-trends.

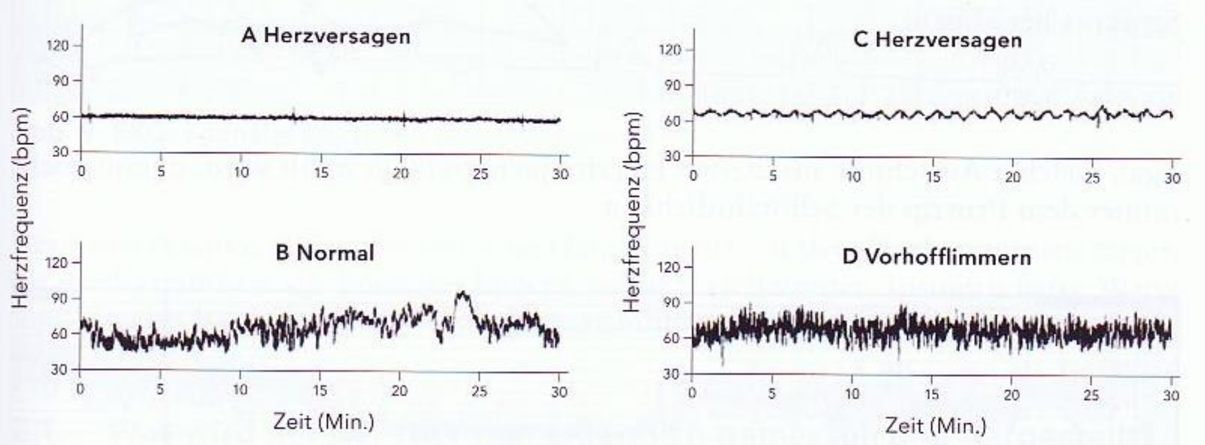

Figure 2: Heart Rate trends [3]

In figure 2 four different heart rate-trends are shown.
On the X-Axis the beats per minute are given and on Y-Axis the time in minutes is given. In example A and C a heart failure is shown.
In example B the trend of healthy heart is recognizable.
In example D a chaotic trend is shown which is caused by an atrial fibrillation. [3]

2.1.1 History of HRV

The importance of HRV was first discovered by Wang Shuhe a Chinese doctor. He lived between 180 – 270, in the Han dynasty. In his writings he mentioned "If the pattern of the heartbeat becomes as regular as the tapping of a woodpecker or the dripping of rain from the roof, the patient will be dead in four days."

Tough the first real documented observation of the HRV was later. Stephan Hales. (1677 – 1761) observed with arterial puncture a breath dependency between blood pressure and pulse of a horse.

Later, Siegmund Mayer (1842 -1910), Ludwig Traube (1818-1876) and Ewald Hering (1834 - 1918) described the occurence of spontaneous fluctuations in blood pressure, which were distinct slower than the heart frequency.

In the year 1921 John Newport Langley introduced the term of autonomic nervous system and classified it in sympathetic, parasympathetic and gastrointestinal.

Six years later Karel Frederik Wenckebach (1864 -1940) and Heinrich Winterberg (1867 - 1929) described the Respiratory Sinus Arrhythmia (RSA) as indicator for a healthy heart function.

1932, Berta Willhelmson (1869-1965) discerned the miss of RSA as accompanying symptoms of cardiovascular problems.

For the next ten years the foundation of subsequent researches were laid with the support of automated heart frequency records.

1963,Edward H. Hon and S.T. Lee noticed that in fetal intrauterine stress mutations, RR-Intervals occurs before a significant change of heart frequency were registered.

M.M. Wolf and his colleagues found a significant coherence between diminished HRV and postinfarct lethality.

In the year 1996 the *Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology* made standards for acquisition and clinical-application of HRV, which have validity till today. [3]

2.1.2 HRV today

Today HRV-Analysis has found many more application possibilities besides treatment of cardiac insufficiency patients and to optimize training adaptations of pro athletes.

HRV-analysis also applies in treatment of depressions, burn-out, and hypertension.
It is also prevalent in the hobby field too; today it's possible to get useable HRV results by using a smartphone camera.

In the paper with the title:" *Statistical analysis of Heart Rate and Heart Rate Variability monitoring through the use of smartphone cameras* "by Bolkhovsky, J.B. , Scully, C.G. and Chon, K.H. the results of an iPhone 4s, Motorola Droid and a 5 lead electrocardiogram for comparison, were written down. Following parameters were recorded: Heart Rate, Low Frequency Power, High Frequency Power, ratio of Low to High Frequency Power, standard deviation of the RR intervals, and root mean square of successive RR-differences. The results show that accurate Heart Rate Variability parameters can be obtained from a smart phone camera. [4]

In the paper from Peng Zhou, Fangfang Sui , Anqiong Zhang , Fang Wang and Guohui Li with the topic „*Music therapy on Heart Rate Variability*", the influence of music to Heart Rate Variability is examined. The results show that during the music treatment the patients get in a relaxed state. After the music therapy the Heart Rate Variability increases significant in Very Low Frequency range (VLF), Low Frequency range (LF) and High Frequency range (HF), while the LF / HF ratio has no significant change. [5]

HRV also gets applied for comparison of different treatment options on the function of the automatic nervous system for hypertension patients, written in the paper: "*Spectral analysis*

of *Heart Rate Variability in treated and untreated patients with essential hypertension*" by Antolic, G. Sega, S. and Kiauta, T.
In this study were several groups with different approaches of hypertension treatment: The first one was chemically treated with atenolol, the second group had a chronic treatment with nifedipine, the third group hadn't any treatment, as reference served, a group of healthy people. One of the results of the study was that there were no significant differences between control subjects and untreated patients.
Another result was that a depression of indices of sympathetic activity in atenolol-treated patients approved the hypothesis that a central mechanism of action contributes to the hypotensive action of atenolol.The chronic treatment with nifedipine did not appreciably modify the sympathovagal balance. [6]

2.1.3 HRV as business model

Nowadays some companies discovered the Heart Rate Variability as business model like the company AUTONOM HEALTH with "Lebensfeuer".
They offer a profound and precise analysis of the health state of the patient via a 24h HRV record. The analysis can be made through a web based access to their "Lebensfeuer" Software. The sensor for the record can be borrowed directly from AUTONOM HEALTH or a trained AUTONOM HEALTH Professional in local area.

This HRV analysis can have benefits for athlets, trainers, sportclubs, professionals, companies, health-conscious people, etc.

Their name of the product "Lebensfeuer" indicates the result of the 24h heart rate variability record in graphical form.

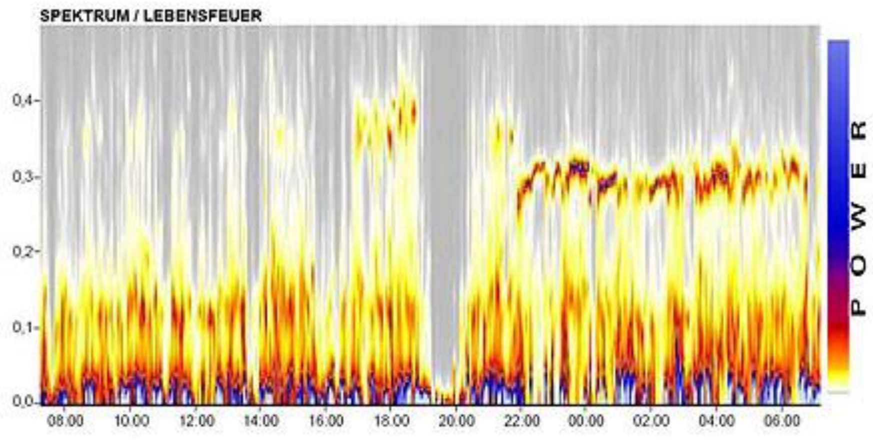

Figure 3: Spectogram_Lebensfeuer [7]

This graphical illustration shows the spectrogram of Very Low Frequencies, Low Frequencies and High Frequencies of the heartbeats during the 24h HRV record. These frequencies will be explained in more detail in chapter 2.1.6.

Besides the HRV-Analysis they offer trainings to get a AUTONOM HEALTH Professional which is equated as partner of the company. These are allowed to make HRV analysis, diagnoses and coaching’s.

2.1.4 HRV parameters

The HRV parameters can be classified in two classes: HRV parameters in time domain and HRV parameters in the frequency domain analysis.

2.1.5 Time Domain Analysis

The Time Domain Analysis contains a descriptive statistic of the successive RR- Intervals (also called NN-Intervals) and their differences. Therefore they are suitable for the comparison and interpretation of the results. In studies these following parameters are used.

1.) SDNN is the Standard Deviation of all RR-Intervals and it is sensitive on changes of the average heart frequency through position or activity. The Standard Deviation describes the autonomic activity. The SDNN is only suitable for comparison when the measuring time and the activity level between the patients are the same. The higher the activity levels all the more the SDNN.

Based on studies the SDNN is used as a prognostic factor after myocardial infarction.
The Multicenter-Post-Infarction-Research-Group-Study has following results:
SDNN<50ms lethality 34,4% - strong limitation of HRV
SDNN<100ms lethality 9% - middle limitation of HRV

The ATRAMI study [8] with 1284 patients after infarction has following results:
SDNN<70ms – 3,2 fold mortality risk
Constrained baroflex – higher mortality risk
Cardiac insufficiency – yearly mortality 50% with SDNN <50ms (5% with SDNN>100ms)

For the interpretation of the SDNN the physical activity level is important. If the SDNN is under 100ms during average lifestyle activities, this is a sign for constrained HRV. Like all other HRV parameters the SDNN underlies also the age dependence. [3]

The formula for the calculation of SDNN is:

$$SDNN = \sqrt{\frac{\sum(RRi - RRmean)^2}{n}}$$

Where:
RRi = RR-Interval
RRmean = Mean Value of all RR-Intervals
n = number of RR-Intervals

2.) RMSSD is the square root of the average sum of the quadratic differences between neighboring RR-Intervals. It's a good indicator for the parasympathetic nervous system. [3]
The formula for calculations is:

$$RMSSD = \sqrt{\frac{\sum_{i=1}^{i=n-1} Di^2}{n-1}}$$

The calculation for the successive differences is:

$RR_{n-1} – RR_n = D_{n-1}$

Where i = interval index
n = number of total intervals
n - 1 = number of interval differences

3.) NN50 is the number of pairs of successive NNs that differ by more than 50ms.
But this parameter gets often expressed in percentage terms of the overall NN Intervals, then its called **pNN50.**

There is a strong correlation between High Frequency Range and pNN50%. So it's a good indicator for the parasympatic activity and also impervious against artefacts. Depending on current situation of the patient with cardiac degeneration a pNN threshold with 20ms can be more sensible than the classical pNN50%. [3]

4.) SDSD is the Standard Deviation of the Successive Difference between neighboring RR-intervals [9]. The successive differences can be calculated like:

$RR_{n-1} – RR_n = D_{n-1}$

Therefore the formula for the SDSD is:

$$SDSD = \sqrt{\frac{\sum_{n=1}^{i=n-1}(Di - Dmean)^2}{n-1}}$$

Where:

i = interval index

n = number of total intervals
n- 1 = number of interval differences

2.1.6 Frequency Domain Analysis

The Frequency Domain Analysis is a method to identify the frequency components of the Heart Rate Variability. It can give information about the coupling of respiration and heartbeat relaxant state. If the respiration and heartbeat are good coupled then the spectral analysis shows a peak. The frequency components in the HRV-Analysis are divided in three components. [10]
There are also many parameters, but one of the most interesting is the LF/HF – Index.

1.) **Very Low Frequency**
Frequencies in spectrum of 0,00 till 0,04Hz are attributable to sympathetic mediated hormonal influences on the sinus node and the activity-related thermoregulation of the body. [3]

2.) **Low Frequency**
Frequencies in spectrum of more than 0,04 till 0,15Hz are attributable to the parasympathetic and sympathetic nervous system activity. Parasympathetic influences are only in lower breathing frequencies. Additionally, this spectrum represents the activity of the baroreflex. [1]

3.) **High Frequency**
Frequencies in spectrum of more than 0,15 till 0,40Hz are attributable to respiratory sinus arrhythmia (=RSA), which is the breathing synchronic variation of the heart frequency. This is also an indicator of the parasympathetic nervous system activity which denotes “rest and digest” behaviors [11]

4.) **LF/HF – Index**
The LF/HF- Index is often an expression of the vegetative balance of parasympathetic and sympathetic activity. That is not quite correct, the HF-component can be attributable to the parasympathetic nervous system.
The LF-component consists of parasympathetic and sympathetic nervous system activity. Therefore, the higher the value the more activity in the sympathetic nervous system. [1]

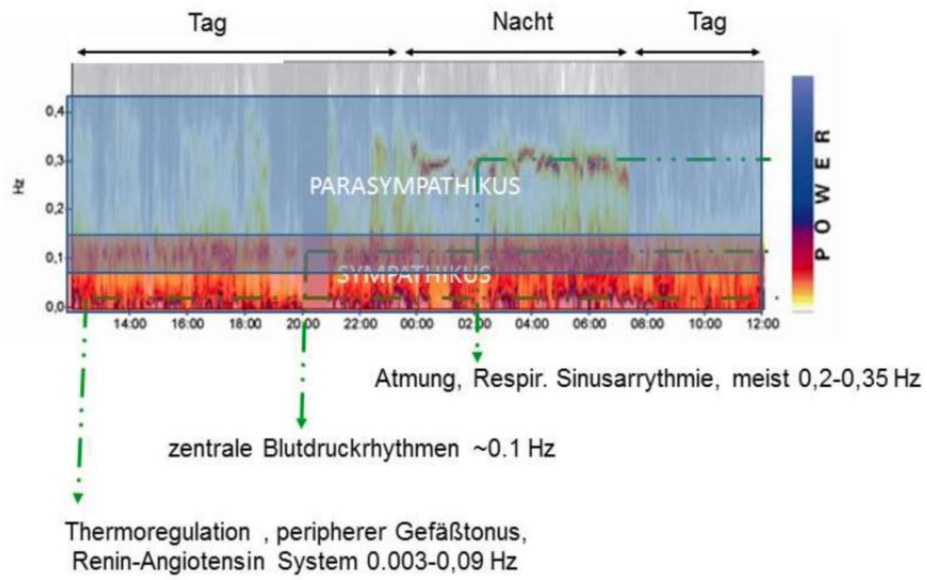

Figure 4: Spectogram_explanation_Lebensfeuer [12]

In figure 4 a spectrogram of a 24h HRV record is shown. Additionally the three frequencies components and the activity of the parasympathetic and sympathetic nervous system are marked out.

2.2 AsTeRICS

AsTeRICS (Assistive Technology Rapid Integration & Construction Set) is a flexible and affordable construction set for developing user driven Assistive Technologies (AT). It offers a framework for finding a specific individual solution for patients.
Emerging sensor techniques like Brain-Computer Interface and Computer Vision can be combined with basic actuators. This makes it possible to help people with reduced motor capabilities to get access to the Human-Machine-Interfaces (HMI) at the standard desktop but also of embedded system devices like mobile phones or smart home devices.

AsTeRICS is easy to use, it offers three types of building blocks for AT:
1.) Sensors which make it possible to measure any controllable body or mind activity to interact with HMI.
2.) Actuators for interfacing with standard IT, or embedded systems.
3.) Plugins for data process with the sensor
The whole software suite is open source, so the system is affordable for many people who cannot benefit from leading edge supportive tools today. [13]

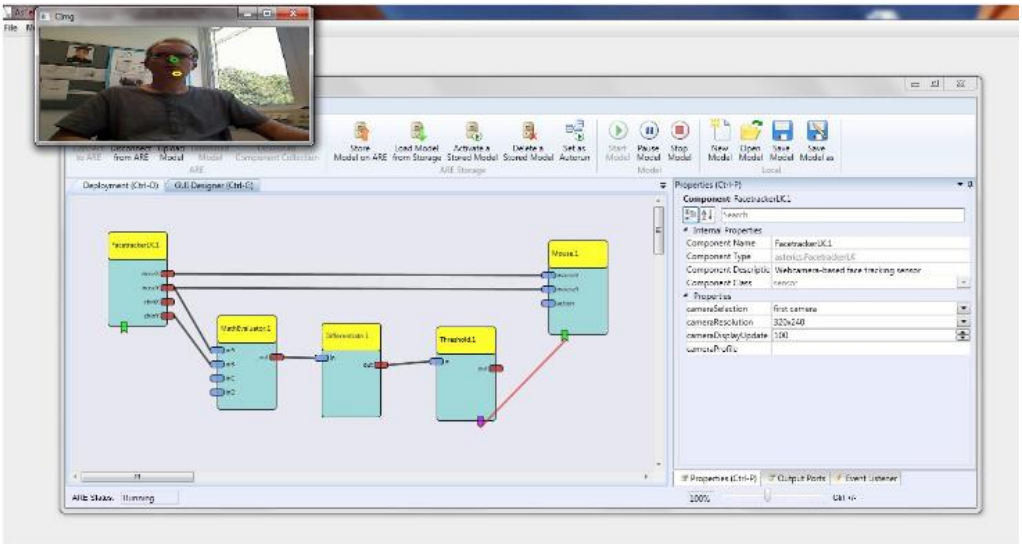

Figure 5: AsTeRICS Configuration Suite with Facetracker plugin [14]

The figure 5 shows the software construction kit, where the sensors and actuators can be connected. In this case a Facetracker is built for moving the computer mouse. Patients can control the mouse by turning their head. The markers indicate nose and chin position.

2.3 OPI True-Sense Kit

OP Innovations offers an affordable, ultra-compact, ultra-low-power, bio-signal measuring DIY Kit, which allows capturing bio feedback on different body parts with wireless data transfer. It is possible to capture EEG, ECG, EMG signals, motions and postures. With these capabilities it is comparable to expensive products like EEG, ECG monitors.
The OPI True-Sense Kit has a low-noise, high gain input amplification with 13bit dynamic range. It supports approximately 24 hours of continuous wireless transmission or 11, 4 hours recording with memory module. The special algorithm which is implemented, allows a collision-free synchronized integration of multiple sensors. [15]

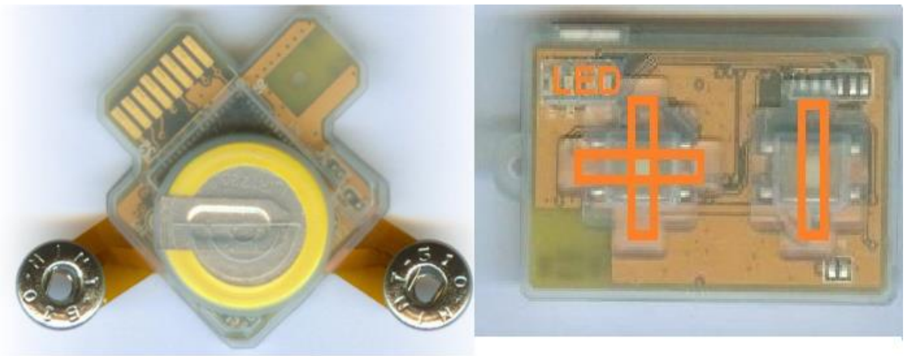

Figure 6: OPI True-Sense Kit contains sensor (l.) and controller (r.) [15]

Figure 6 shows the OPI True-Sense Kit, which contains the sensor and controller.
In operation, the controller works as master and the sensor as slave which is necessary for the wireless data transmission.

Figure 7 shows different locations on the body for bio feedback. It is possible to measure alpha and beta waves, left and right brain activity, HRV, breathing, etc.

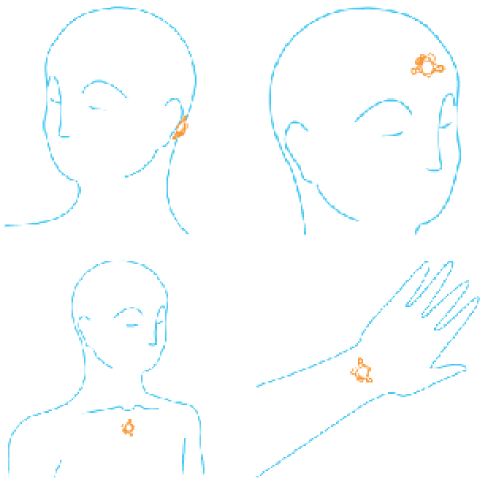

Figure 7: Body locations for OPI True-Sense Kit [14]

2.3.1 Conversion of an analog signal to a digital signal

From analog ECG signal to digital signal following stages have to be paced.
The electrical stimulation of the sinus node runs over the conduction system of the heart to the muscles of the heart which initiates the pumping function.
This change of electrical potential of the heart can be measured via the electrodes of the OPI True-Sense Sensor on the skin surface. [16]

These changes of electrical potential are in a micro voltage area, so the signal has to be amplified and afterwards filtered. Via the A/D – Converter the analog signal gets converted into a digital one. These digital signals get transmitted via the wireless transmission protocol ZigBee (chapter 2.3.2) to the controller. The controller transmits the signal over USB to the computer, and then the signal can get analysed.

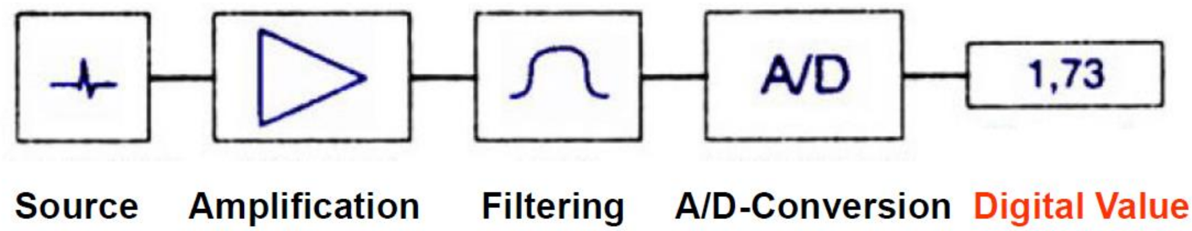

Figure 8: Measurement Chain [17]

For a useful digital signal it's necessary to sample the analogue signal at least with double rate of the fastest frequency contained in the signal, after the Nyquist-Shannon sampling theorem. [18] In practice the sample rate is often higher than the double rate of the fastest frequency in a signal.The OPI True-Sense Sensor has a sampling rate of 512Hz, therefore only signals with a maximum frequency of 128Hz can be captured without any aliasing artefacts.

2.3.2 ZigBee

The OPI True-Sense Sensor uses ZigBee as wireless data transmission protocol between sensor and controller. ZigBee is an industry standard for wireless data transformation. It gets used in building automation, medical engineering and automation engineering with distances of 10meters to 100meters. ZigBee builds on the standard IEEE 802.15.4 and is a further development of the ZigBee alliance. The standard fits on the OSI Model introduced standard IEEE 802.15.4 specified OSI-Sub layers PHY and MAC.

The ZigBee standard allows three different roles of device types: terminal device (used within True-Sense Sensor), Router and Coordinator. [19]

3 Practical Part

The practical part of the thesis deals with the development of two plugins for the AsTeRICS framework. The first plugin implements the communication from the sensor to the PC and the second plugin implements the specific HRV variables for analysis.

3.1 Implementation of OPI True-Sense Protocol

For communication between the OPI True-Sense Sensor and PC, the specific OPI Link Protocol [20] has to be implemented. The protocol is for asynchronous serially data streams.

In Figure 7 the packet structure is shown.

Figure 9: Structure of OPI Link Protocol [20]

Two sync bytes, each with a value of 0x33, are denoting the beginning of a packet.

Two further bytes are reserved for the payload length. The minimum payload size is 0, and the maximum is 65535. Practically the payload length is never larger then ~1k bytes because of the limited RAM of the OPI True Sense Sensor. The payload length is in Big Endian Format. The payload contains the date.
At the end is the checksum with two bytes. It’s created only from the payload data. The bytes of the payload are summarized and the lower 16 bytes of the sum are used for the checksum. The checksum is also in Big Endian format.

The OPI Wired Frame [21] assumes a master-slave association and doesn’t need to be “wired”. “Wired” in this context means, that data is not prone to corruption and error. Therefore only non-corrupt data is used.

In Figure 8 the structure of the OPI Wired Frame is depicted.

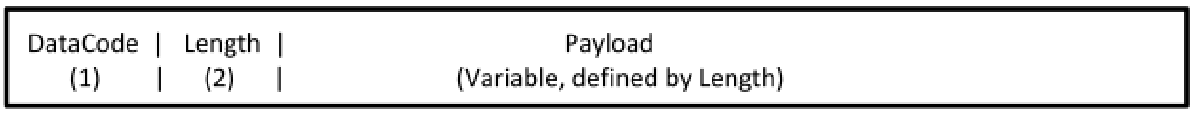

Figure 10: OPI Wired Frame definition [21]

The data code with 1 byte specifies the type of data contained in this frame. Currently 16 possible codes exist but for implementation in future 255 codes are possible.

The length specifies the payload length in bytes in Big Endian Format.

The payload contains the current data. The format is specified by the data code, that's why the size is variable and can be up to 65532 bytes. Usually the payload is only a small fraction of the maximum.

Before mess data can be received, two steps are necessary.

Step1:To turn on the sensor via order, the following byte array has to be transmitted: {0x33,0x33,0x00,0x02,0x20,0x23,0x00,0x43}. The sensor replies on this request a status response with OK or NOK. When the sensor is OK a request for data transmission has to be sent. For details see Figure 9.

Data Code	Sub-Data Code (payload[0])	Payload Length (bytes)	Description	Payload Format (bytes)	S/M
0x20	0x22	1	Go to "off" state		M
0x20	0x23	1	Go to "on" state		M
0x40		0	OK		S
0x41		0	Not OK		S

Figure 11: State_on/off and Status_OK/NOK [21]

Step2: Request for data transmission has to be sent. Following byte array has to be transmitted: {0x33, 0x33, 0x00, 0x02, 0x10, 0x00, 0x00, and 0x10}. The sensor replies on this request with a transmission of one mess data packet. For an ongoing mess data transmission the request has to be send frequently.

This packet includes the timestamp of transmission, device number of sensor, ADC values, temperature etc. The packet has a size of 145/141 bytes. For details see Figure 10.

Data Code	Sub-Data Code (payload[0])	Payload Length (bytes)	Description	Payload Format (bytes)	S/M
0x01	0x01	145/141	Interpreted/Fixed Received Wireless TrueSense Data	Timestamp (6); Wireless Frame PDN (1); Wireless Frame Misc (1); ADC Channel 0 64/62 13.5b samples (128/124); Temperature Code (1); Accelerometer (6); ED Measurement (1);	S
0x10	0x10	1	Request wireless measurement of current channel from slave		M

Figure 12: Data_Request and True-Sense_data [21]

Following functions have to be implemented in the code of the first plugin:

1.) Opening of right COM-port which is created by the controller unit of the OPI True Sense Development Kit on the computer.

2.) Turn on sensor and send frequently requests for data transmission.

3.) Receiving of packet and parsing.

4.) Forward ADC values to output port of the plugin.

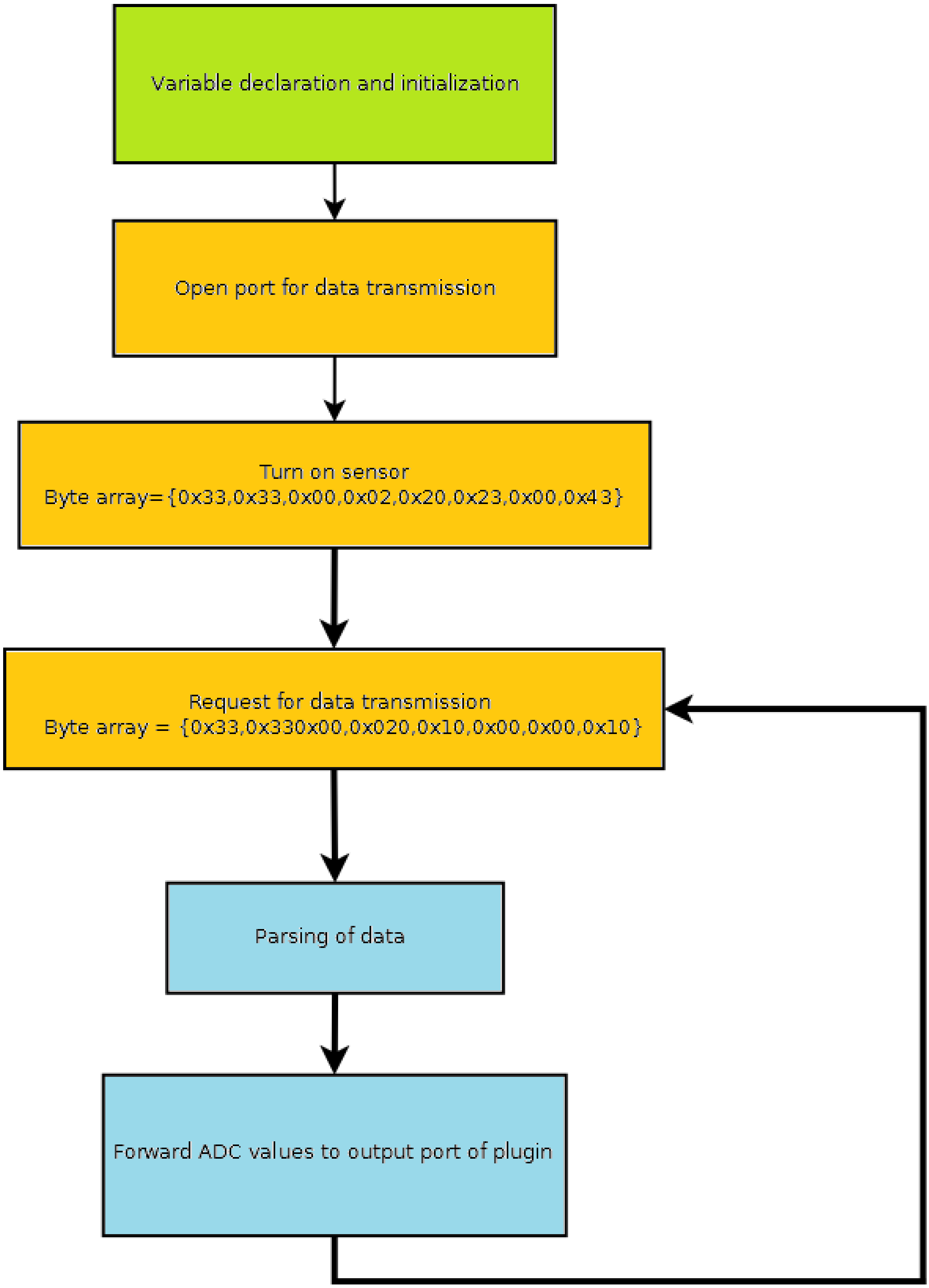

Figure 13: Dataflow diagram Truse Sense plugin

3.2 Implementation of HRV Analysis

The HRV analysis plugin is far more complex than the True-Sense Plugin.

The main objective of this plugin is to check the incoming measurement data for heartbeats and calculate the HRV parameters and forward them to the specific output ports.

Following parameters are available on the output ports: actual pulse, SDNN, RMSSD, SDSD, PNN50, PNN20 and DRRI (= Difference of the actual RR-Interval to the previous RR-Interval).

Because of the constantly changing heartbeat it's necessary to adapt dynamically the checks of validation of the heartbeat and filter of artefacts. Therefore the algorithm calculates the mean value of duration, size of the heartbeat, and also of the intervals. When the heartbeat is too small/high, or the duration is to short, or when the interval to the last heartbeat is too short, the heartbeat doesn't advert in the calculations of the parameter and gets treat as artefact.

For the correct calculations of the RR-Intervals a timebase is needed. For this reason it's possible to type in the sampling rate of the sensor.
When the program starts the time from the system will be taken and with every incoming measurement sample the time will be increased, depending on the sample rate of the sensor. In case of the True-Sense-Sensor its 512Hz, so 1,953125ms will be added with each incoming sample.

The plugin works as state machine and has seven phases.

The first phase serves as **idle phase** and for preparation for the next phases. In this phase the sensor can be stacked on the body and checked if a correct heartbeat signal appears. When the correct phase is found the initial phase can be started via the Start button in the ARE (=AsTeRICS Runtime Environment).

The initial phase has a duration of five seconds. In these five seconds three to six heartbeats (depending on patient's condition) should be measured. The highest positive peak of an R-wave and the lowest negative peak will be saved. From these sample the ranges to detect a heartbeat will be calculated .The range is necessary to find a trigger point where a possible heartbeat begins or ends.

Additionally a check for an inverted signal is made if the sensor is stacked twisted on the body, the signal will be inverted. After that check the state of the program changes to "**Selection**".

In this state the incoming samples get checked if they are over the range for a possible heartbeat or under the range of Tale. If they are over the range for a possible heartbeat the state changes to **"Peak**". If they are under the range of Tale the state changes to "**Bottom**". When the samples are between those two ranges nothing happens.

In the state "**Peak**" the plausibility check for the heartbeat is realized.
First the duration of the heartbeat is measured and checked if it's in a valid length.
Second the size of the R-peak is checked if it is in the possible range.
At least the duration of the interval to the last R-peak is checked, if it's in the valid range.
All the reference values for the plausibility checks are calculated in the state:" R-peaks calculations".

If one of the checks is false, the wrong detected heartbeat is treated as artefact and does not slip in the parameter calculations.
When the checks are true the state changes to "**R-peaks calculations"**.
In this state the mean value of duration, size of the heartbeat and the actual RR-Interval gets calculated for future checks of plausibility.
Then the program continues with the calculation for the actual pulse, SDNN, DRRI, SDSD, RMSSD, PNN50, PNN20 and starts. After that the state changes back to "**Selection**", and the next samples are checked for peak or bottom.
In the state "Bottom" the lowest value of the signal gets saved.
Then the program switches to the state "**Bottom Calculations**".
In this state the range for the tale detection is calculated. Then the state changes back to "Selection".

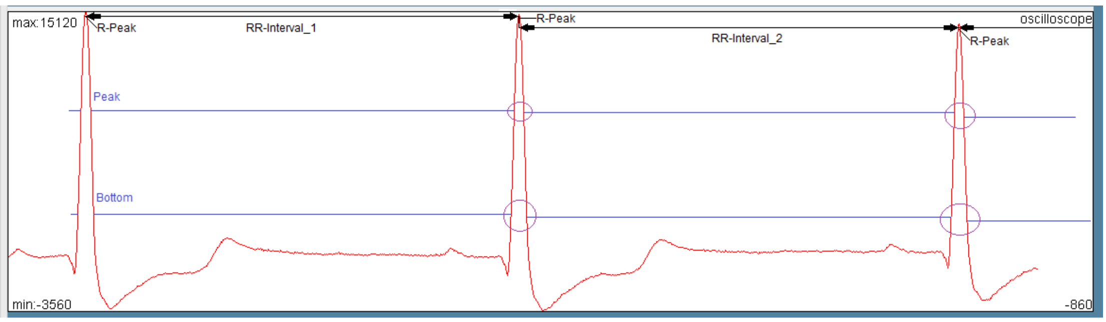

Figure 14: Ranges for detection

In Figure 14 the signal is displayed via Oscilloscope, ranges for detection of Mountain and Tale, the RR-Interval and the height of the R-Peak are fine-drawn. The purple circles indicate the adaption of the borders.

Figure 15: Dataflow_diagram_HRV_Analysis

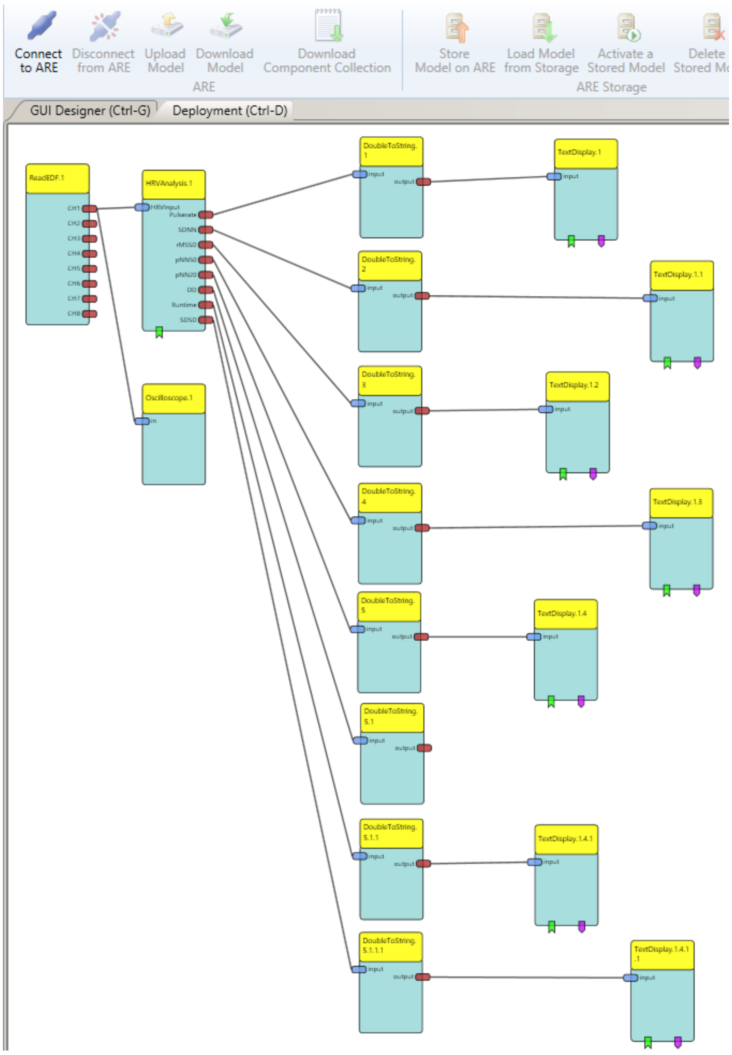

Figure 16: HRV_Analysis_ACS

In Figure 15 the implemented plugins are shown as working AsTeRICS model
The signal of the True-Sense Sensor is sent to the Input port of the HRV Analysis module and for visualisation. The parameters of the output port of the HRV Analysis module are connected with a double to string module. This is necessary for the Text Display modules. The text display module allows displaying the values during runtime. See Figure 16.

4 Measurement result

For the test of the application a ten minute HRV was recorded.
The record was made while sitting in front of the PC in the morning.

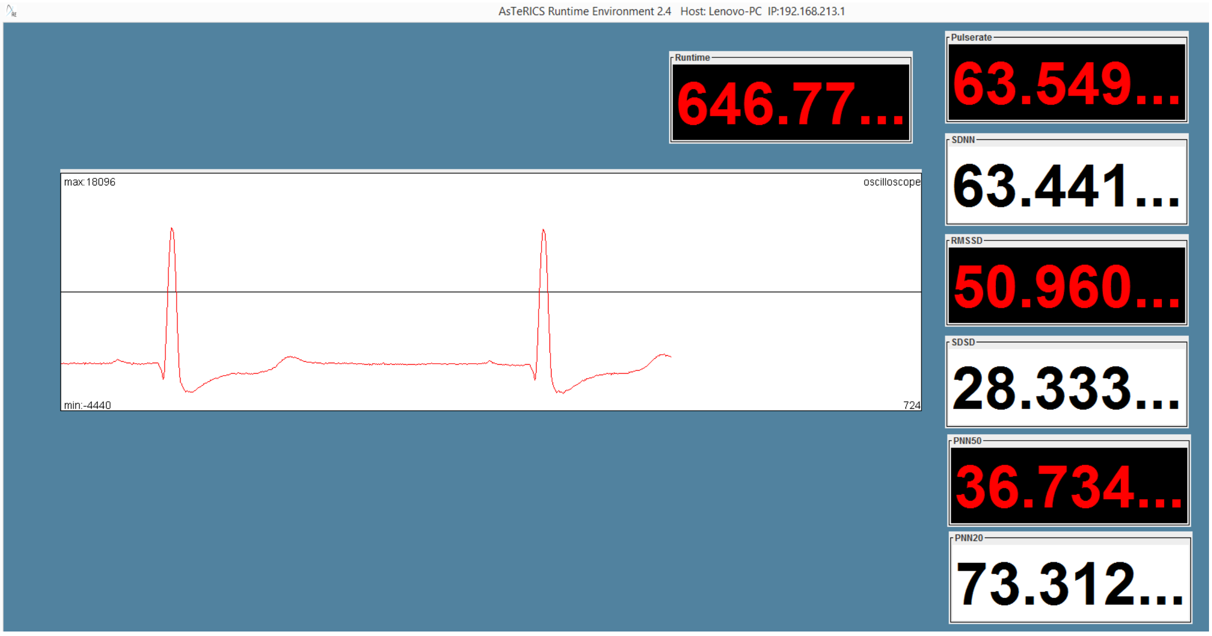

Figure 17: Result of 10mins HRV record

The duration was 10minutes and 27 seconds.
The pulse was 60 beats per minute.
SDNN was 63ms.
RMSSD was 51ms.
SDSD was 28 ms.
PNN50 was 37%.
PNN20 was 73%.

For this value a study [22] from the *Taskforce of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology* serves as reference values.

In this study the age, sex and environment were omitted but are nevertheless useful for an approximate comparison.
The published normal values are:
(Normal value + Standard deviation)
SDNN: 141+39ms.
RMSSD: 27+12ms.
SDANN: 127+35ms.
Normal values for SDSD, PNN50 and PNN20 were not listened.
Values of the spectral analysis are also listed in the study but are not necessary for the

comparison.
As we can see a ten minute record is not adequately for a good comparison.
The value for SDNN is far away from the norm range, the RMSSD is over the range.
For a better comparison the normal values for men and for the age of 24 years would be more descriptive.

5 Discussion

The task of the thesis to develop a basic HRV analysis system with good signal recognition was successful but there is a lot of room for improvements.

A graphical illustration of the HRV like the “Lebensfeuer” figure would be impressive.
In this program an output of the actual difference of the RR-Interval is implemented, so with a subsequent plugin it would be possible to illustrate.

The HRV analysis offers many more parameters which are necessary for a more detailed analysis also for non-expert people like the biological age of the body, LF/HF Index which indicates if the body is in a tense or relaxed state etc.
In this work only the basic parameters has been implanted.

It’s possible that packages which consists a peak get lost, because of a transmission error therefore for a better quality of HRV an interpolation of a lost peaks can be implemented.

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