AN OVERVIEW ABOUT ELECTRONIC BABY MONITORS USED IN SLEEP MEDICINE

DATA ACQUISITION METHODS AND ELECTRONIC SENSING PRINCIPLES

Raul Kala

TAL TECH
KIRJASTUS

ISBN: 978-9949-83-668-0
ISBN: 978-9949-83-669-7 (pdf)
Trükikoda: Koopia Niini & Rauam

PREFACE

There is no point in discussing the importance of sleep to our quality of life. In general, this relationship is sufficiently clear and acceptable.

Unfortunately, sleep therapy is more difficult for a particular person because we all have different physical and mental health conditions related to both the need and the specifics of sleep. Deciding on needs and the extent to which they will be met, requires assessments. Specifically, in order to obtain objective results, we need measurements for evaluation using suitable and approved measuring instruments. In this context, technology, especially electronics and information technology, is taking steps to solve sleep problems.

The author has tried to explain to doctors the possibilities of technology and vice versa – the needs of doctors to engineers. The author's efforts to promote mutual understanding between medicine and engineering deserve the attention of both parties in order to achieve common success.

Mart Min

Professor Emeritus, Medical Electronics

Tallinn University of Technology

THE AIM OF THE BOOK

Everybody knows the noise the babies can make and therefore think that it is better to be in quiet. However, total silence can be much bigger cause of trouble when You don't know what is going on. Therefore baby monitors have been designed, in order to monitor the sound they make, the video and physiological signals like heart rate. This book describes how electronic baby monitors have been designed, what kind of signals they measure and what kind of signal processing methods are in usage. The book consists of 6 chapters what describe the history, data aquisition and the usage of the sensors. The emphasis of the book is to ask, if there is anything what can be done to measure the sleeping patient in a non-contact way and preferably at home. We all know what are the polysomnographs, what they measure and how accurate they are but there is still little knowledge about the home-usage electronic devices. I would like to thank all my friends who have helped me.

Raul Kala, MSc in Electronics and Biomedical Engineering
Founder member of Estonian Sleep Medicine Association

Contact: raulkala@gmail.com

ACKNOWLEDGEMENT

I am very thankful for Professor Emeritus, Medical Electronics, Mart Min from Tallinn University of Technology who wrote the preface for this book.

I would like to thank my great friend PhD Jüri Vedru from the University of Tartu, who read the book and corrected the mistakes.

INTRODUCTION

Electronic baby monitors have been in usage for long time. However, the first baby monitors were able only to monitor the sound and the video signal and therefore people found little interest in the usage of them. Within ages electronics has become more advanced, being more able to monitor complex signals, process and store them. Because of that electronic baby monitors have advanced and become able to measure many signals and transmit them over the internet. Because of these advancements we have to ask ourselves what have been done, what is possible to do today and what can be done in the future. Are there any possible errors and mistakes to be avoided? What happens when someone hacks into your baby monitor? Does it cause a lot of serious trouble? There are more questions than answers.

Chapter 1, Historical overview about electronic baby monitors used in sleep medicine

This is the shortest chapter of the book. This chapter shows where the topic has found it's beginning. Who came up with these ideas and what caused the advancement. Additional data can be found from patent descriptions. Also, searching for old photos can give a lot of valuable information. Sometimes a look of a picture can open some kind of new world, new paradigmas what to explore.

Chapter 2, The device specification

You have an idea – You want to design a baby monitor. However, there are always questions to be asked, like: what?, how? and why? Because of that this chapter asks what are the most common types of the baby monitors and how to design them. Also this chapter shows what kind of parameters and values can be expected from user manuals.

Chapter 3, Types of electronic baby monitors

This chapter describes the following types of baby monitors: audio monitors, video monitors, smart beds, mattresses, pillows, incubators and wireless body area networks. The main aspect is based on the fact how these monitors are designed. There are many references and they can be used as additional materials.

Chapter 4, The signals of the electronic baby monitors

This chapter describes 3 aspects about the signals: the most common characteristics of the biosignals, the biosignals measured by the electronic baby monitors and data storage and compression related issues. This chapter includes some information about the noise, amplitude, phase, frequency and vectors. Of course there are errors and mistakes to be considered – what they are what to do. The biosignals measured by the electronic baby monitors describe the ECG, respiration rate, temperature, audio, pulse oxymetry and video signals. The data storage and compression related issues are meant for situations when there are huge amounts of data recorded within huge amounts of timings.

Chapter 5, The academic aspect: the thesis

It is always interesting to know how people think in different universities and what they consider to be important. Because of that there is a chapter what describes the thesis about electronic baby monitors, the universities, the supervisors, degree and year. This chapter is short in length now but certainly it will grow with time.
Chapter 6, The statistics, data analysis & signal processing

This chapter gives some basic knowledge about signal processing, it reminds some important equations and gives some recommendations about what kind of books to read. Among other things, the fuzzy logic principles and artificial neural networks are mentioned here. From the electronics side of view, the operational amplifiers and the complex impedance are mentioned here.

Appendix 1, The measurements

Ok, You have the theory now. What to do next? How do baby monitors in your local shop look like? This appendix describes some of the baby monitors you can buy and how big is the electric field emitted by them.

CONTENTS

CHAPTER 1

HISTORICAL OVERVIEW ABOUT ELECTRONIC BABY MONITORS USED IN SLEEP MEDICINE

HISTORICAL OVERVIEW ABOUT ELECTRONIC BABY MONITORS

In every field of science, there are some paradigmas what define the field. Usually this is some kind of person's need for something and trying to find a solution. The same is also true about baby monitors. At first nobody seemed to need a such a device like a baby monitor. However, things changed a lot after a kidnapping event that happened in 1932 (Stephens, 2018). That dramatic event inspired Eugene McDonald to deisgn the first baby monitor, the Radio Nurse, what consisted of the child and parent unit and transmitted 1-way audio signal (https://babymonitorcenter.com/history-of-baby-monitors). The Radio Nurse became available in 1937 (Stephens, 2018) but lasted only until 1938 because the device's design was bad and the device did not work well (https://babymonitorcenter.com/history-of-baby-monitors).

When new baby monitors were designed, it become evident that the devices were prone to radio signal interference (https://babymonitorcenter.com/history-of-baby-monitors). By that time Frequency Hopping Spread Spectrum (FHSS) was invented in 1941 by Hedy Lamarr and Georg Antheil and the usage of FHSS helped to make baby monitor's data transmission more secure but it took a lot of time before baby monitors started using FHSS (https://babymonitorcenter.com/history-of-baby-monitors).

In 1965 digital signal processing was developed and gave room for digital baby monitors (https://babymonitorcenter.com/history-of-baby-monitors). Later the baby monitors became video monitors (https://www.ligo.co.uk/blog/a-brief-history-of-the-baby-monitor/). Within years the baby monitors became more and more advanced. For example, there are baby monitors what are named as infant cry detection system with automatic soothing and video monitooring (Silva, 2017). After many scientists and engineers hard work during the decades it became evident that the electronic baby monitors can be classified among other principles as bed based, room based and the person based baby monitors (Kala, 2016).

References

A Brief History of the Baby Monitor – liGo Blog –liGo Magazine
https://www.ligo.co.uk/blog/a-brief-history-of-the-baby-monitor/, 10.09.2015

History of Baby Monitors
https://babymonitorcenter.com/history-of-baby-monitors

Kala, R., 2016
Electronically Equipped Beds Used In Sleep Medicine, Tallinn University of Technology, 2016, ISBN 978-9949-83-013-8

Silva, G.V.I.S., 2017
Infant Cry Detection System with Automatic Soothing and Video Monitoring Functions
Journal of Engineering and Technology of the Open University of Sri Lanka (JET-OUSL), Vol.5, No.1, 2017, 36-53.

Stephens, C., 2018
The chilling story behind the invention of the first baby monitor
https://www.mamamia.com.au/baby-monitor-history/, July 9, 2018

CHAPTER 2

THE DEVICE SPECIFICATION

2.1 THE MOST COMMON TYPES OF THE BABY MONITORS

2.2 THE QUESTIONS TO BE ASKED: WHAT?, HOW? AND WHY?

2.3 THE TECHNICAL DETAILS: THE USER MANUAL APPROACH

2.1 THE MOST COMMON TYPES OF THE BABY MONITORS

In every field of science, there is a question how to define the field of interest. Certainly one has to ask himself what are the main questions what define the problem. What is of primary concern and what is secondary? What kind of parameters need to be measured? What kind of problems have been reported earlier? Is there any alternative solution? Because of that, this chapter tries to define the design of the most used types of baby monitors. The following picture, Figure 1. defines 4 types of monitors: audio monitors, video monitors, incubators and smart textile based body area networks (BAN). Considering today's smartness, this picture includes one hard to define element, the internet-of-things (IoT). Today many baby monitors use the internet feature but this is not the most essential part of classification.

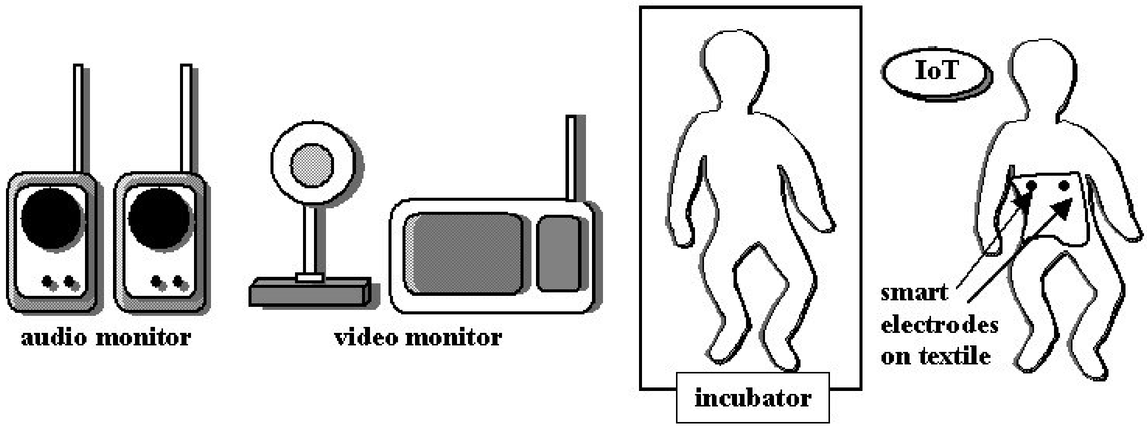

Figure 1. *The most common types of baby monitors.*

This figure describes 3 types of monitors what the parents use (audio, video and smart textile based BAN) and the one used in the hospitals (incubator). The audio and video monitors are most common among parents. Although smart textile based BAN systems exist, they are not widely spread. It may be because smart textiles and smart electrodes have been on the market for only some time. Also smart beds, mattresses and pillows can be used as baby monitors (see Chapter 3).

2.2 THE QUESTIONS TO BE ASKED: WHAT?, HOW? AND WHY?

It is nice to be aware of some kind of classification but the problem is, that the classi-fication is never 100% reliable and it changes within time passing. Therefore the designer has to ask himself several questions in order to find out the most important parameters. Because of it, 2 tables have been created. Table 1 asks the what, how and why questions and Table 2 describes the different qualities of the signals. One has to keep in mind that these 2 tables do not represent the ultimate truth and it is recommended to advance these tables with questions on the board by the time of solving the problem. The ability to ask right questions can lead to much faster and more advanced design. The What-column asks questions about the signals to be measured. The human being offers many possibilites to measure many different signals. When non-contact electronic measurement devices are used, heart and breathing rate signals become most important.

The How-column asks questions about the ways how the signals should be aquired. There are many biomedical engineering books what offer a lot of knowledge about the sensors and electrodes. The How-column also includes the signal processing topic because the data aquistion and analog-to-digital conversion is not always enough. There are always problems about noise interference, extracting one signal from another, saturation, offset and other types of error and misfunction what need to be solved with signal processing.

The Why-column asks the designer once again – why this signal is needed? Is it a big or a small problem? For example when heart beating or breathing stops, it is a very big problem and time is calculated in seconds. Under such circumstances, right acting is of paramount importance and alarm signaling is recommended (sound, light).

The Problem-topic asks the designer, what are the problems when the device (monitor) is ready. Is it a user interface problem or is it a safety problem? What happens to the patient when the problem is not solved? Is it leathal? Does it affect other people as well? Finally one has to taken into account some hidden problems like data privacy. Some baby monitors may offer some cloud-service and special software for monitoring the sleep data but in case of leaking this can also lead into serious privacy issues. So, one has to think, what is the most important issue and what can be neglegted.

What ?	How ?	Why ?	Problems
• breathing rate • heart rate • body temperature • audio • video • room temperature • bed wetting	• microphones • video • textile electrodes and smartclothes • smart mattress and bed exit detection • door opening and exiting detection	• heart beating stops • breathing stops • crying or no sound at all • somebody trying to steal the child	• data encryption • hacking • electrical safety

Table 1. *The questions to be asked.*

There is always a problem considering the fact what kind of parameters to measure and what kind of sensors to use. Different sensors give different signals and therefore there is no best solution what can be always recommended. The following table, Table 2 describes 2 important parameters to be measured – the heart rate (HR) and the breathing rate (BR) and offers ideas about non-contact sensors to be used. The other 2 parameters, temperature and pressure offer additional information, for example information about staying in the bed. The temperature and pressure signals are easy to measure with many different sensors and the exact value of the signal is not important. However, these "simple" signals may become important when you want to make sure that the child is still in the bed, has not crawlen out or being stolen. Also there are always environmental issues what need to be considered. For example a CO_2 sensor is always recommended.

In a way or another, when a biomedical device is designed, signal specific characters have to be kept in mind. Here the signals and parameters refered to are meant to give information about some kind of warning but the situation becomes more complicated when a diagnostic purpose is kept in mind. Therefore it is recommended to collect information about measurable signals from specific committees.

parameter	sensor	signal
heart rate	Foucault current sensor, capacitance sensor	complicated and valuable
breathing rate	Foucault current sensor, capacitance sensor	complicated and valuable
temperature	IR, RTD, thermistor	easy to measure, some value
pressure	load cells, FSR, electromechanic film, PVDF	stay in bed, little value

Table 2. *How parameters, sensors and signals match with each other.*

2.3 THE TECHNICAL DETAILS: THE USER MANUAL APPROACH

In order to describe the technical data in a more detailed way, data from 2 user manuals is taken. The author has no conflicts of interests with any of the products. This data is shown in order to describe what has been used and what kind of parameters are expected. It is certain that once this data becomes old and loses it's value but here the main aspect is to show what kind of parameters and values belong together, into the same "family". Usually a single user manual offers very little valuable information about the technical details, so a collection of many manuals is recommended. Also, one should keep in mind that the user manuals don't offer the ultimate truth. For example, usually it is unknown under what conditions the measurements were made and because of it may happen that a newly designed monitor does not reach to the values offered by the user manual. Because of it, the user manual should be used as an another helping link. Unfortunately the user manuals don't offer information about the microcontrollers used and signal processing, so this information has to be collected from the articles.

2.3.1 THE VIDEO MONITORS

Usually video monitors offer sound and video transmission, night vision, camera zoom, snapshot and app features (https://www.safety.com/baby-monitors). Some video systems inform the parents with the message sent through the GSM Network (Clenisha et al., 2018). The video cameras usually offer signal range about 1000 feet and battery life about 8 hours (https://www.babylist.com/hello-baby/best-baby-monitor). Typically the video monitor consists of one camera unit and one monitor unit but also there are multiple camera systems (Summer Infant Inc, 2014). However, one should keep in mind that with every camera there are blind spots what can not be detected and because of this the camera does not replace the nanny. The video signal processing can be very comilicated. Sometimes specific Red, Green and Blue cameras are used for data fusion (Cattani et al., 2017). Usually microcontrollers are used for video signal processing but there are also systems what use Arduino or Raspberry Pi systems (Symon et al., 2017). In order to overcome problems with darkness IR cameras are recommended. The following table, Table 3 offers some "typical" information about the video monitoring system's camera and monitor unit, taken from a user manual (www.denver-electronics.com). There are many technical details, imprtant for the designer, for example information about the image sensor used, number of pixels and effective working range. Also one has to pay attention to the transmitting power and keep it under the safe limits.

Camera	parameter	Monitor	parameter
Image sensor	CMOS	Screen Type	2.4 ‘ TFT LCD
Effective pixels	640*480	Screen Resolution	320*240
Viewing angle	35*	Data Bandwidth	3 MHz
Night Visual Range	< 2m	Transmission Speed	3 Mbps
AF Sensitivity	< -38 dB	AF Sensitivity	< -38 dB
Transmitting Freq	2400-2483,5 MHz	Working Frequency	2400-2483,5 MHz
Transmitting Power	17+- 2dBm	Transmitting Power	17+ - 2 dBm
Receiving Sensitivity	-80 dBm	Receiving Sensitivity	-80 dBm
Modulation Mode	GFSK	Modulation Mode	GFSK
Unobstr Effective Range	200 m	Unobstr Effective Range	200 m
Working Voltage	DC +5V	Working Voltage	DC +5V
Working Current	300 mA(Max)	Working Current	450 mA(Max)
Working Temperature	0 C -- + 40 C	Working Temperature	-10 C – +40 C
Working Humidity	15% -- 85% RH	Working Humidity	15% -- 85% RH
Dimension L*W*H	57x57x100 mm	Dimension L*W*H	106x66x23 mm

Table 3. *The user manual of 2.4GHz Wireless Baby Cam with 2.4" TFT Display On Monitor Model: DENVER BC-241, www.denver-electronics.com*

2.3.2 THE AUDIO MONITORS

The audio signal transmission itself is another field of science because there are so many ways how to detect, amplify and transmit the signal. Today a lot of information about the audio signal amplification and processing can be found from electronics handbooks (Horowitz & Hill, 2001). The most of the human speech lies in a small range of Hz, from 300 Hz – 3400 Hz in the phone range and therefore many different microphones can be used. The audio signal amplification by itself is simple, there are lot’s of audio circuits in the handbooks/circuit collections what offer different yet simple audio amplification methods with 1 or 2 transistors. However, signal processing can turn the things to be complicated (Silva, 2017). The following table, Table 4, offers little information about the audio baby monitor, taken from a user manual. Although there are only some parameters mentioned, it should be noticed that the usage of the crystal-controlled PLL and superheterodyne help to keep the audio signal very clean.

Transmitter	parameter	Receiver	parameter
circuitry	Crystal-controlled PLL	circuitry	Single superheterodyne
Frequency range	902,200-904,900 MHz		
Number of channels	27		
Modulation system	FM		
Power requirement	AC adapter, 120 V AC, 60 Hz	Power requirement	AC adaptor, 120 V AC, 60 Hz
		Audio power output	110 mW, 40 mW using 2.4 V DC
		Speaker	57 mm dia, 16 Ω
Dimensions	101,8x99,5x63 mm	Dimensions	94x109x59 mm

Table 4. *The sound monitor’s user manual, Sound-Sensor Nursery Monitor Operating Instructions, NTM-910DUAL*

References

Cattani et al., 2017
Monitoring infants by automatic video processing: A unified approach to motion analysis
Computers in Biology and Medicine 80 (2017), 158-165

Clenisha et al., 2018
Survey on automated child monitoring system using image processing,
International Journal of Pure and Applied Mathematics,
Volume 118 No. 24 2018, ISSN: 1314-3395 (on-line version)

Symon et al., 2017
Design and Development of a Smart Baby Monitoring System based on Raspberry Pi and Pi Camera,
Proceedings of the 2017 4th International Conference on Advances in Electrical Engineering, 28-30 September, 2017, Dhaka, Bangladesh
978-1-5386-0869-2/17, 2017 IEEE

Horowitz & Hill, 2001
The Art of Electronics,
Cambridge University Press, 2001, ISBN: 0 521 37095 7

Silva, G.V.I.S, Wickramasinghe, D.S., 2017
Infant Cry Detection System with Automatic Soothing and Video Monitoring Functions
Journal of Engineering and Technology of the Open University of Sri Lanka (JET-OUSL), Vol. 5, No. 1, 2017

Summer Infant Inc, 2014
www.summerinfant.com, Clearsight Duo Digital Color Video Monitor, instruction manual

www.denver-electronics.com

https://www.safety.com/baby-monitors

https://www.babylist.com/hello-baby/best-baby-monitor

CHAPTER 3

TYPES OF ELECTRONIC BABY MONITORS

3.1 AUDIO BABY MONITORS

3.1.1 INTRODUCTION

Audio baby monitors have the longest history and because of the simple design they are most well spread. There are many ways how to define the audio baby monitor. One can see the audio baby monitor as another piece of amplifier-transmitter-receiver design and also one can see audio baby monitors as another sub-field of bio-telemetry. Considering the signal transmission aspect, the audio baby monitors are designed as RF-devices. However, as we will see from Figure 1, RF with all of it's modulation methods is not the only signal transmission method.

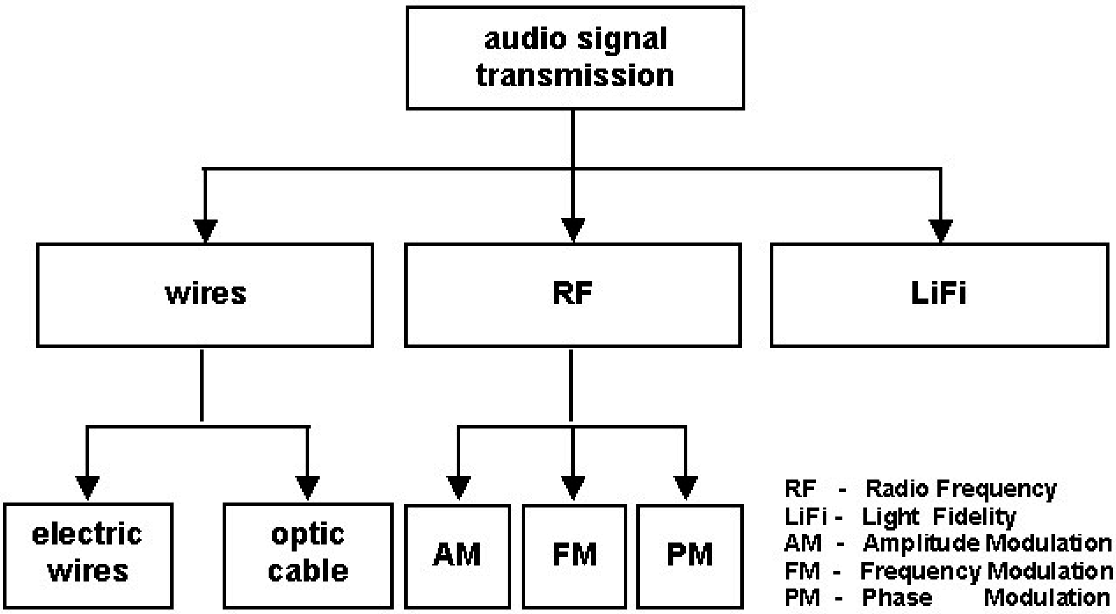

Figure 1. *Audio signal transmission methods.*

A design, what uses electric wires as the signal transmission medium, is certainly simple but the signal transmission distance is limited and also the wires are suspectible to RF and EMI noise/interference. The electric wires need proper shielding. The optic cable offers possibilities to transmit the signal without any loss or RF/EMI interference but it demands the usage of the signal modulation-demodulation. The optic cable can offer high data rates.

Here typical RF-signal transmission and receiving principles are mentioned but not described in detail. There are several books what describe basic RF-signal transmission and receiving principles, like (Horowitz & Hill, 2001), (Johnson & Fletcher, 1997) and (Nikita, 2014). Light-Fidelity is a signal transmission method where the electric signal is modulated into light signal, transmitted through air and when demodulated into electric signal (Haas et al., 2015). The father of the Li-Fi technique is Harald Haas (Kate et al., 2017).

3.1.2 RF-AUDIO BABY MONITORS

The RF-audio baby monitors can be classified into 2 big classes: the walkie-talkie types and the cry detectors. The walkie-talkie type of RF-baby monitors only transmitt sound, either in simplex or duplex mode without any further signal processing. The cry detectors detect the pitch of the baby's voice and process it and according to the situation detected, they might or might not start an alarm. In principle the RF-audio signal transmission can be realized with the usage of either analog or digital signals. Because of the security threats and also the signal processing, digital audio signal transmission has gained a lot of popularity. For example, there are many audio baby monitors what use Digital Enchanced Cordless Telecommunication (DECT) signal transmissioon (Philips Avent SCD510/00, VTECH DM221). Considering the many different audio signal transmission aspects, there is always a possibility to either choose a design by yourself or buy some previously designed and manufactured signal transmission modules. One such kind of modules, a 433 MHz signal transmitter and receiver module is shown on Figure 2. In the market, there are many such kind of devices for many different frequencies, power rates and launch distance parameters, just to mention a few of them. Like usual, both approaches have their pros and cons.

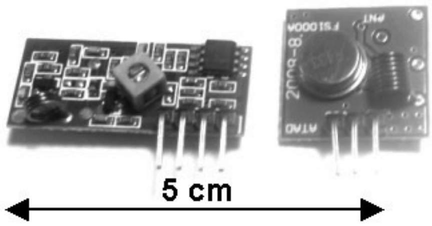

Figure 2. *A 433 MHz receiver (XD-RF-5V) and transmitter (XD-FST) set.*

So far the signal transmission aspect has received the most of the attention. The signal transmission aspect is important not only because of the device's own working but also because of the kinky side-effects it can have – it may cause interference to the hearing aids. Of course, there are also many other important aspects like amplification, filtering and signal processing. There are many well-designed chips what perform all of these previously mentioned issues but here the 3.3/5 V operating voltage sets the limits.The microphone and the amplifier have to be well matched otherwise there is not enough voltage for ampli-fication. The powering of the baby monitors is usually done with the usage of the batteries but they last approximately 6-10 hours and because of it some baby monitors also use mains powering but the usage of the mains powering needs extra safety. Because of the marketing demands, even simplest audio monitors can have extra additions like lightning LEDs and lullaby singing with songs being previously stored in a device's memory.

The walki-talkie baby monitors

These baby monitors can be designed in many different ways. Sometimes you can buy a set of walkie-talkies and discover that they have a baby monitor function (the SM2493 user's manual). Also these baby monitors can be designed by re-using old smart phones (Paul et al., 2017). The usage of the smart phones gives a possibility to create a multple client-server data collection method. In general, these monitors only monitor the sound and don't do any signal processing. However, not all of the RF-audio baby monitors monitor the baby's voice continously, sometimes the user has the ability to set the sound detection level.

The cry detectors

The cry detectors use many different signal processing methods and also many different activities. For example there are cry detectors what send out an SMS-message after the baby's cry has been detected (Naiknaware et al., 2017). There are articles what put emphasis on analog electronics (Ji-hui & Quan, 2014), digital signal processing (Reddy et al., 2014) and comprehensive whole system descriptions (Silva & Wickramasinghe, 2017). The articles written by (Silva & Wickramasinghe, 2017) and (Reddy et al., 2014) are based on the usage of the MATLAB and describe the usage of the MFCC(Mel Frequency Cepstrum Coefficients), pitch frequency, K-NN (K-Nearest Neigbour), Magnitude Sum Function (SUM), Zero Crossing (ZC), Energy and Short Time Auto Correlation (STAC).

References

H. Haas et al., 2015
What is LiFi?,
Journal of Lightwave Technology, IEEE, 2015,
Digital Object Identifier 10.1109/JLT.2015.2510021

Horowitz & Hill, 2001
The Art of Electronics,
Cambridge University Press, 2001, ISBN: 0 521 37095 7

Ji-hui & Quan, 2014
Design and Implementation of the Crying Voice Detection Circuit In The Baby's Supervision System,
Review of Computer Engineering Studies, Vol. 1, No. 1, 2014, pp. 13-16

J.J. Johnson & B.D.Fletcher, 1997
Introductory Radio and Television Electronics,
Macmillan, 1997, ISBN: 0-333 61656-1

D.M. Kate et al., 2017
Li-Fi Technology: A Real Time Data Transmission Using Visible Light Communication,
International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 6, Issue 6, June 2017, ISSN (Online): 2278-8875

Naiknaware et al., 2017
Review on Baby Monitoring System,
IJCSN International Journal of Computer and Network, Vol. 6, Issue 2, April 2017, ISSN (Online): 2277-5420

K.S. Nikita, 2014
Handbook of Biomedical Telemetry,
IEEE Press, 2014, ISBN: 978-1-118-38861-7

J.F. Paul et al., 2017
Infant Monitoring Using Old Smart Phones,
IOSR Journal of Mobile Computing & Application (IOSR-JMCA),
e-ISSN: 2394-0050, P-ISSN: 2394-0042, Vol. 4, Issue 2, Mar.-Apr. 2017, pp. 01-04

Reddy et al., 2014

Baby Monitoring Through MATLAB Graphical User Interface,
International Journal Of Scientific & Technology Research, Vol. 3, Issue 7, July 2014, ISSN: 2277-8616

Silva, G.V.I.S, Wickramasinghe, D.S., 2017

Infant Cry Detection System with Automatic Soothing and Video Monitoring Functions
Journal of Engineering and Technology of the Open University of Sri Lanka (JET-OUSL), Vol. 5, No. 1, 2017

User manuals

Philips Avent SCD510/00
http://attachments.content4us.com/datasheets/DATASHEET_SCD510_ENG.PDF

SM2493
http://disneywristart.com/instructions/Gifts%20and%20Gadgets/Science%20Museum/SM2493%20-%20Walkie%20Talkie%20Set.pdf

VTECH DM221
https://usermanual.wiki/Vtech/VtechSafeAndSoundDm221UsersManual392093.1486538059/view

3.2 VIDEO BABY MONITORS

3.2.1 INTRODUCTION

In essence, the video signal transmission needs 3 components: the video camera, the transmission system and the display where the moving picture is presented. The video camera's history includes many important dates, starting from the Joseph May's discovery of the photoelectric effect in 1873 and when advancing in many different ways (J.J. Peters, 2000). In 1875 George Carey in USA came up with an idea of using many photoelectric cells in matrix layout and in 1881 Constantin Senlecq in France came up with a similiar idea (J.J. Peters, 2000). The first camera tube, so called "the iconoscope" was developed by Vladimir Zworykin and manufactured by the RCA in 1929 in USA (http://www.uv201.com/Tube_Pages/iconoscopes.htm). The first electronic cameras were built in 1936 for Berlin Olympic Games (J.J. Peters, 2000). The "iconoscope" advanced in the 1940s and became known as the "Vidicon" (http://www.uv201.com/Tube_Pages/rca_vidicon.htm).

The Vidicon is a special electronic lamp device what uses photoconductive material as a light detectioning sensor. In 1969 Willard Boyle and George Smith from the Bell Labs invented solid state charge coupled device (CCD) (Smith, 2010). The CCD cameras are very well spread. In the early 1990s the CMOS image sensors were developed (Fowler et al., 2006). Also, there are Quantum Dot sensor cameras. The research history about Quantum Dots dates back in 1982 when Arakawa and Sakaki did their research about semiconductor lasers (Martyniuk & Rogalski, 2008). In general, the most widespread video signal sensors are shown in Figure 1.

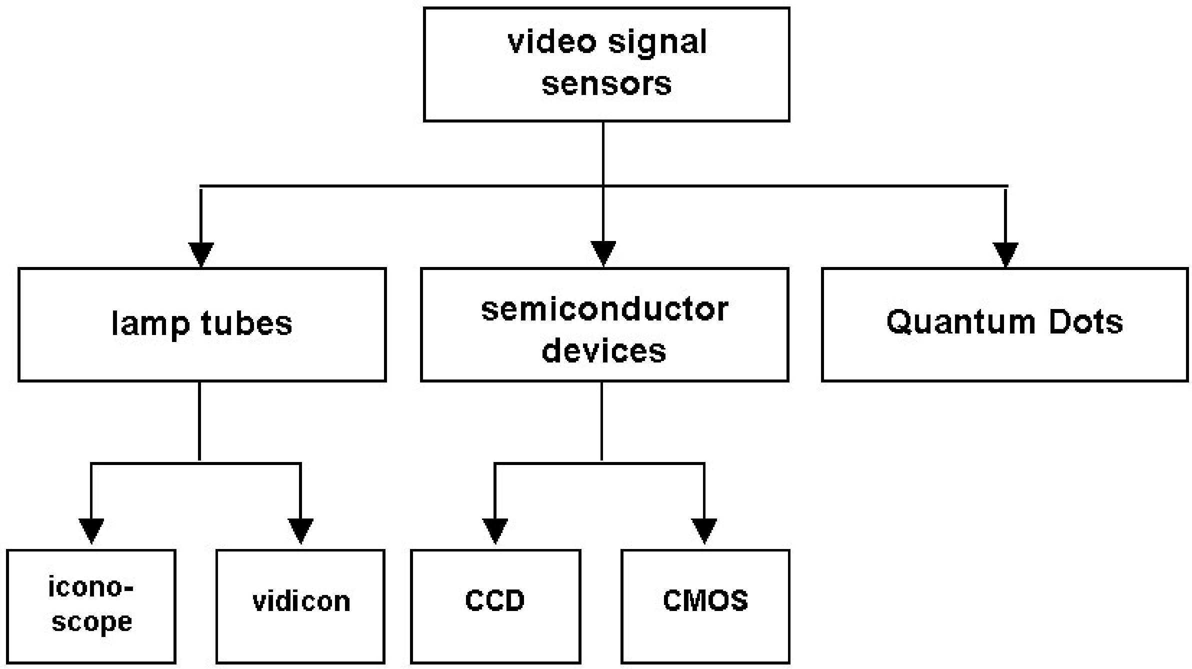

Figure 1. *Most widespread video signal sensors.*

The display’s history started in 1897 when Karl Braun invented the cathode ray tube (CRT) (Johnson & Fletcher, 1997). In 1964 Heilmeier’s research in the RCA Laboratories led into the development of the liquid crystal display (LCD) (Kawamoto, 2002).

Today video equipment is almost entirely digital and therefore the following concentrates only on digital video equipment. There are lot of parameters what help to understand the digital video system but here are only some most important parameters to be mentioned.The quality of the digital video depends on the sensor’s resolution, recording rate (frames per second), the number of colours and also about the qualities of the display system. In order to make things more difficult, one should keep in mind that all of these parameters are dependent of each other and also affect the size of the data storage. The folllowing pictures display the working principles of the monochrome (Figure. 2) and the colour video camera (Figure. 3) and the usage of the IR-illuminator (Figure. 4) during night time recordings.

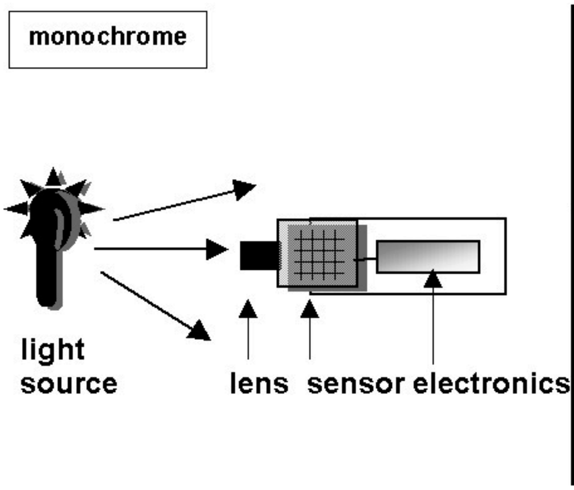

Figure 2. *The monochrome(black and white) video camera’s working principle.*

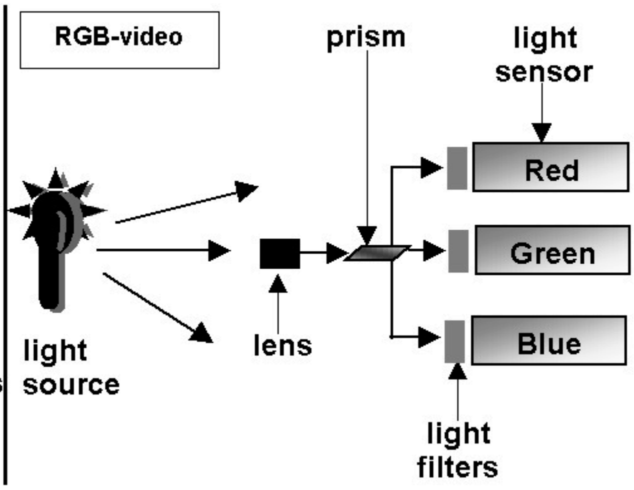

Figure 3. *The RGB-colour video camera’s working principle.*

The monochrome camera records video in black and white format. In such a case, light entering the lens interacts with the sensor and the electronics circuitry converts it into different levels of grayness.

The RGB-video camera records 3 colours: Red, Green and Blue and the colour vision is the result of mixing these three colours. However, some display systems use different colouring model, the CMYK – Cyan, Magneta, Yellow, Black colour model instead of the RGB model and because of it there can be huge changes in the image look a likeness.

Recording video during the night time can be very complicated. The night time image recording can be improved a lot with the usage of the Infra-Red (IR) illuminator device. On Figure. 4 the IR camera and IR illuminator are displayed separately but they can be integrated into one single device.

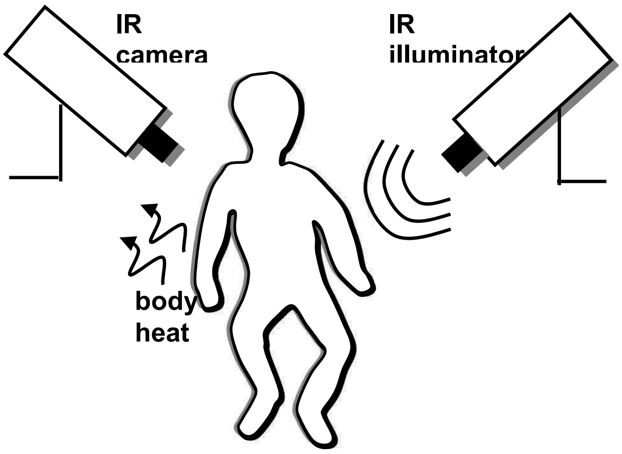

Figure 4. *The usage of the IR-illuminator.*

The video recording also includes problems related to the usage of multiple cameras and multiple monitors and also signal distortion problems. This can become a problem in places where multiple patiensts need surveillance like in hospitals. Although the whole video monitoring system can't be totally automated, software detecting sudden body movements or sudden colour / brightness changes can save a lot. If possible, the video software system should be able to detect a crisis situation and send out an alarm message.

3.2.2 EXISTING VIDEO RECORDING SYSTEMS

The video recording systems fall into 2 big classes: systems based on Raspberry Pi's (Symon et al., 2017, Sundar et al., 2017, Silva & Wickramasinghe, 2017) or Arduino's (Clenisha et al., 2018) components and systems using RGB-cameras (Torres et al., 2018, Cattani et al., 2017) and more complicated hardware and software. This classification can be easily understood because Raspberry Pi / Arduino systems use simple, cheap and well-spread hardware and have a lot of code examples. However, when more complicated signal processing is the aim, these systems may suffer from various hardware and software weaknesses one has to buy more expensive cameras and write more specialized software for them. The following describes these previously mentioned systems in more detail.

The Raspberry Pi based systems

A system designed by (Sundar et al., 2017) uses 4 PIR sensors for tracking child's movements and when using the data to rotate the camera. This is done in order to avoid possible blind spots. The system uses Wi-Fi router for transfering the video signal over internet. Also the system uses GSM-module for sending out SMS alerts.

A system designed by (Symon et al., 2017) uses condenser microphone (LM393), PIR motion sensor and camera as the sensors and LCD display and buzzer alert as output devices. The PIR sensor is used for tracking child's movements and guiding the camera's movements. The microphone is used for detecting crying. The system uses Pyhon's script.

A system designed by (Silva & Wickramasinghe, 2017) uses camera, microphone and Wi-Fi module connected to the Raspberry Pi system. The microphone is used for detecing crying. The system uses Raspberry Pi compatible 5 Megapixel camera module with the usage of the Camera Serial Interface (CSI). The Wi-Fi module is used for transmitting the data to the parent's mobile phone.

The Arduino based systems

A system designed by (Clenisha et al., 2018) uses camera, LCD and GSM-module connected to the Arduino.

The RGB-camera systems

A system designed by (Cattani et al., 2017) is used for detecting seizures and apneas. The systems uses Maximum Likelihood criterion for detecting pathological body movements. The system uses standard RGB cameras. The video is sampled with period T and frames are numbered. Each frame is described by a matrix of W x H pixels. Each frame is first converted into grayscale, then FIR filter is applied. After that spatial luminance signal is calculated. A single RGB camera with conversion to grey is used for detecting apneas. The system used 3 different cameras and different combinations of these 3 cameras.

A system designed by (Torres et al., 2018) uses a camera attached to an incubator and monitors the neonate's diaphragm. The method is based on tracking colour intensity variations on the neonate's diaphragm. Firstly the video is recorded, when the area of interest is selected and each image is separeated into its colour components. Next the pixels in each frame are averaged. The signal is filtered with Short Time Fourier Transform (STFT). The resolution of the video was 1920 x 1080 or 1280 x 720 pixels with frame rate 24 or 30 frames per second. The images were saved in AVI or MP4 format. The signal processing was done in Matlab. The abdominal area is used for tracking because it contains information about heart and breathing rhythm – the intensity level of pixel brighness. The area of interest is 40 x 40 pixels and the image is separated into three RGB channels.

The IR-video recording

There is an article describing the usage of the IR-video camera for monitoring the infants (Long et al., 2019). The video and PSG signals were recorded simultaneously. The recusive search (RS) motion detection algorithm was used for detecting motions from the IR-video recordings.

3.2.3. VIDEO SIGNAL PROCESSING

Video signal recording creates huge amounts of data sets and therefore signal processing requires a lot of power and knowledge. Like always, there is no one simple and most effective way for signal processing. However, there are some ideas what have proven to be effective and may find additional usage. The following describes only some ideas and the reader should also keep in mind that there are always more options. Based on a book by (Clarkson & Stark, 1995), there are 3 ideas what can be used for video signal processing and are presented on Table 1.

SIGNAL PROCESSING METHOD	PROBLEM TO BE SOLVED
• Colour matching	What is the smallest adjustment required of a given spectrum to produce colour matching in a colour sensitive visual system ? What combination of basis of colours will produce a match to a particular set of measurements ? What is a parsimonious mixture of colours that when added to a given spectrum will produce a predetermined colour match ?
• Resolution enchancement	How can a series of low-resolution images be combined into a single high-resolution image ?
• Blind deconvolution	Trying to recover a source signal from data which has been distorted by an unknown distorting function.

Table 1. *The signal processing method vs the problem to be solved.*

Also one should keep in mind that there are many nonlinear complex signal processing methods like fuzzy sets or artificial neural networks which are difficult to understand but may give good results. For example there are fuzzy video content-based retrieval methods (Doulamis et al., 2000) and video data analsysis by (L. Cheng, 2017) which uses convolutional neural networks (CNN). The systems uses 2500 images classified into 5 classes and 3 different architectures: ResNet18, AlexNet and SqueezeNet. The best results were obtained with ResNet18.

References

L. Cattani et al., 2017
Monitoring infants by automatic video processing: A unified approach to motion analysis,
Computers in Biology and Medicine, 80, 2017, pp. 158-165

L. Cheng, 2017
Robo-Nanny: ConvNets for Intelligent Baby Monitoring,
June 2017, Stanford University – CS231n Final Project Report

P.M. Clarkson & H. Stark, 1995
Signal Processng Methods for Audio, Images and Telecommunications,
Signal Processing and It's Applications, Academic Press, 1995,
ISBN: 0-12-175790-0

M. Clenisha et al., 2018
Survey on automated child monitoring system using image processing,
International Journal of Pure and Applied Mathematics,
Vol. 118, No. 24, 2018,
ISSN: 1314-3395

A.D. Doulamis et al., 2000
A fuzzy video content representation for video summarization
and content-based retrieval,
Signal Processing 80, 2000, 1049-1067

B. Fowler et al., 2006
CMOS Image Sensors - Past Present and Future
Fairchild Imaging, 1801 McCarthy Blvd. Milpitas, CA 95035 USA,
ICIS '06 International Congress of Imaging Science, Final Program and Proceedings

J.J. Johnson & B.D. Fletcher, 1997
Introductory Radio and Television Electronics,
Macmillan, 1997,
ISBN: 0-333 61656-1

J.J. Peters, 2000
A History of Television
http://arantxa.ii.uam.es/~jms/tvd/tv_history.pdf

H. Kawamoto, IEEE, 2002
The History of Liquid-Crystal Displays
Proceedings Of The IEEE, VOL. 90, NO. 4, APRIL 2002

X. Long et al., 2019
Video-Based Actigraphy for Monitoring Wake and Sleep in Healthy Infants:
A Laboratory Study,
Sensors 2019, 19, 1075; DOI: 10.3390/s19051075

P. Martyniuk, A. Rogalski, 2008
Quantum-dot infrared photodetectors: Status and outlook
Progress in Quantum Electronics 32 (2008) 89-120

Silva, G.V.I.S, Wickramasinghe, D.S., 2017
Infant Cry Detection System with Automatic Soothing and Video Monitoring Functions
Journal of Engineering and Technology of the Open University of Sri Lanka (JET-OUSL), Vol. 5, No. 1, 2017

G. E. Smith, 2010
Nobel Lecture: The invention and early history of the CCD*
Bell Laboratories, Murray Hill, New Jersey 08005-2822, USA
Published 13 August 2010, DOI: 10.1103/RevModPhys.82.2307
REVIEWS OF MODERN PHYSICS, VOLUME 82, JULY–SEPTEMBER 2010

S. Sundar et al., 2017
A Prototype of Automated Child Monitoring System,
International Journal of Computational Intelligence Research,
Vol. 13, Nr. 7, 2017, pp. 1593-1603
ISSN: 0973-1873

A.F. Symon et al., 2017
Design and Development of a Smart Baby Monitoring System based on Raspberry Pi and Pi Camera,
Proceedings of the 2017 4th International Conference on Advances in Electrical Engineering, 28-30 September, 2017, Dhaka, Bangladesh

J.-C. C.-Torres, et al., 2018
Non-Contact, Simple Neonatal Monitoring by Photoplethysmography,
Sensors 2018, 18, 4362; DOI: 10.3390/s18124362

http://www.uv201.com/Tube_Pages/iconoscopes.htm

http://www.uv201.com/Tube_Pages/rca_vidicon.htm

3.3 SMART BEDS, MATTRESSES AND PILLOWS

3.3.1 INTRODUCTION

In general, the smart beds, mattresses and pillows are products manufactured by different companies but in principle they belong into the same family. These smart products present us with data by using non-contact data aquisition principles. The idea of using non-contact sensors sounds great but also causes a lot of problems because people move their bodies while staying in bed and this causes distortions and loss of signal strength. Therefore these signals can’t be used for diagnostic purpouses but for detecting emergencies.

Among the smart devices mentioned, smart beds, mattresses and pillows usually have only sensory electronics. These sensors measure heart rate, breathing rate, temperature and humidity. Smart cradle devices also use sensory electronics but usually it has been advanced by adding a motor to swing the cradle. The sensors used for smart cradle systems use the same sensors and also audio and video sensors. It is quite common that signals detected from the baby are used for sending alerting e-mail or SMS to the parent. Data from the smart systems is collected to the cloud server and used for displaying graphs on smart phones. Also one can say today that e-cradle is just another component of the smart house. This in principle leads us into another topic – how secure is your smart house? Is there any possibility that sensors can be used as means for intruding into your house?

How to integrate devices together? Is it enough when you receive data from only a single smart device? Should the smart bed,mattress, pillow and cradle all communicate with each other? How smart the bedroom is going to be? Do you want to monitor just the baby or the whole family?

Finally there is a question about the data-what are you going to do with all this data? Today data storage is not a problem any more but one has to know how to manipulate all this data. For example, how to make sure that now is the right time to give an alarm. Is the sensor sensitive enough or is it giving false alarms? How to program the microcontroller: is it enough when a usual program is written or should it use fuzzy systems or artificial neural networks?

3.3.2 SMART BEDS

Smart beds usually have 2 special functions: the sensors connected to the bed or actuators used for moving the bed's positions. These 2 functions find full usage with adults but for babies, because of their small size there is no need for cutting the platform into sections. Therefore smart beds designed for babies usually mean that there are video cameras monitoring the bed or pressure sensors placed under the bedposts (Kala, 2016). It is much more reasonable to use either smart mattresses, smart pillows or smart cradles. Among the many smart monitoring devices mentioned, the smart mattresses are the most popular because many different sensors can be connected to or into the mattress and the mattress can be changed. This means that there is no need to replace the whole system, just only the mattress.

3.3.3 SMART MATTRESSES

In the field of smart mattresses, almost all kind of sensors have been used but the only signals what have been reliably aquired, are heart rate and breathing rate. This comes from the fact that the sleeping person moves his body and therefore only the strongest signals can be aquired. For example, the sleeping person moves his body so much that one can't measure body temperature accurately. However, big temperature changes can be used as indicators of leaving the bed. Because of the previously mentioned body movements heart rate and breathing rate can not be diagnostically measured but sudden changes in tempo can be used as valuable alarming indicators.

There are articles (Xie et al., 2018) and dissertations (Verhaert, 2011) what describe how to design mattresses with special ergonomic features and this also means that in the future the sub-field called "smart mattresses" will widen and become more complex.

Research shows that there are smart baby-mattresses having small dimensions but the same electronics like the one used for adult.

3.3.4 SMART PILLOWS

Smart pillows are pillows equipped with electronic devices and they are not well spread. While talking about smart pillows, there are 2 problems: how to keep the head in a single position and how to measure weak signals from the head. Just as the articles have shown to us, there is no simple and most effective solution. There is also another, alternative way of thinking – using pillows and other pieces of furniture as smart communication devices (Patil., 2018) and therefore almost every piece of furniture can monitor something but not always diagnose something. The pillows described in the articles have no special "baby" or "adult" design – the same electronic principles are used for pillows designed for both cases. Because there are so few electronic pillows on the market and also so few described in the articles, a clear classification of smart pillows is not possible. All smart pillows include some kind of sensors but some smart pillows include much more complicated design by using many devices in one system or using complex signal processing methods. Therefore the following list of smart pillows is alphabetical and the classification of devices has to wait it's own time.

An alphabetical but not a complete list of existing smart pillows

A smart pillow by (Boomidevi et al., 2015) includes a ballistocardiographic (BCG) system, force sensitive resistor (FSR) system, respiratory sensor, heartbeat sensor, Zigbee or GSM module and Visual Basic software. The Zigbee module is used for transfering data over short distances and GSM for transfering data over long distances.

A smart pillow by (Jayaraj et al., 2017) is a smart pillow what detects sleep apnea by using oxygen signal.

In an article by (Li & Chiu, 2018) a complex smart pillow and related works is described. The smart pillow consists of 3 temperature and 1 humidity sensors, Fuzzy Logic system, statistical analysis and sending data into the cloud server. The data is used for detecting sweat, fever or insomnia.

A smart pillow by (Man & Bae, 2018) detects the input sound for snoring by using snoring sound classification and spectral features.

A smart pillow by (Rachakonda et al., 2018) measures the number of hours in sleep, the audible range of snoring, respiratory rate, heart rate and then sends the data to cloud for signal processing. After the signal processing the user's stress level is divided into 5 states: High stress, Medium-high stress, Medium Stress, Medium Low stress and Low stress.

There are also complex systems what include many devices, including the smart pillow, just like a system designed by Huijia Health Technology (http://www.huijiahealth.com.tw/, 2019). This system consists of Smart Pillow, Smart Baby Mat, Smart Cushions, Smart Clothes, Continous blood pressure measurements, Smart Walker, Smart Care Bed, Smart Care Film and monitoring devices. The system uses fiber optic cable for detecting physiological parameters.

A smart pillow by (Sakila et al., 2018) monitors temperature, humidity, luminosity, sound and vibration. The pillow also includes a speaker which works as an alarm and a massager and internet connectivity. So, among many other features, this smart pillow can sing relaxing songs an massage the patient in order to improve falling into sleep and also these features can be used as alarming devices.

3.3.5 SMART CRADLE

There are lots of articles describing the smart baby cradle system. In principle the articles describe similiar software and hardware features, so getting an overiew about the smart cradle design is not a big problem. However, there are some articles what describe the topic in more detail and should therefore be mentioned first: a system by (Chao et al., 2015), (Ashraf & Hussain, 2015) and a system by (Gawade et al., 2018). From the signal processing side one should notice a smart cradle designed by (Krishna et al., 2019) which uses a fuzzy classifier. Also, it should be mentioned that there is at least 1 article (Nathan et al., 2018) what gives an overview about 22 previously made electronic cradle systems. The whole smart cradle system can be integrated into one picture, as seen in Figure 1.

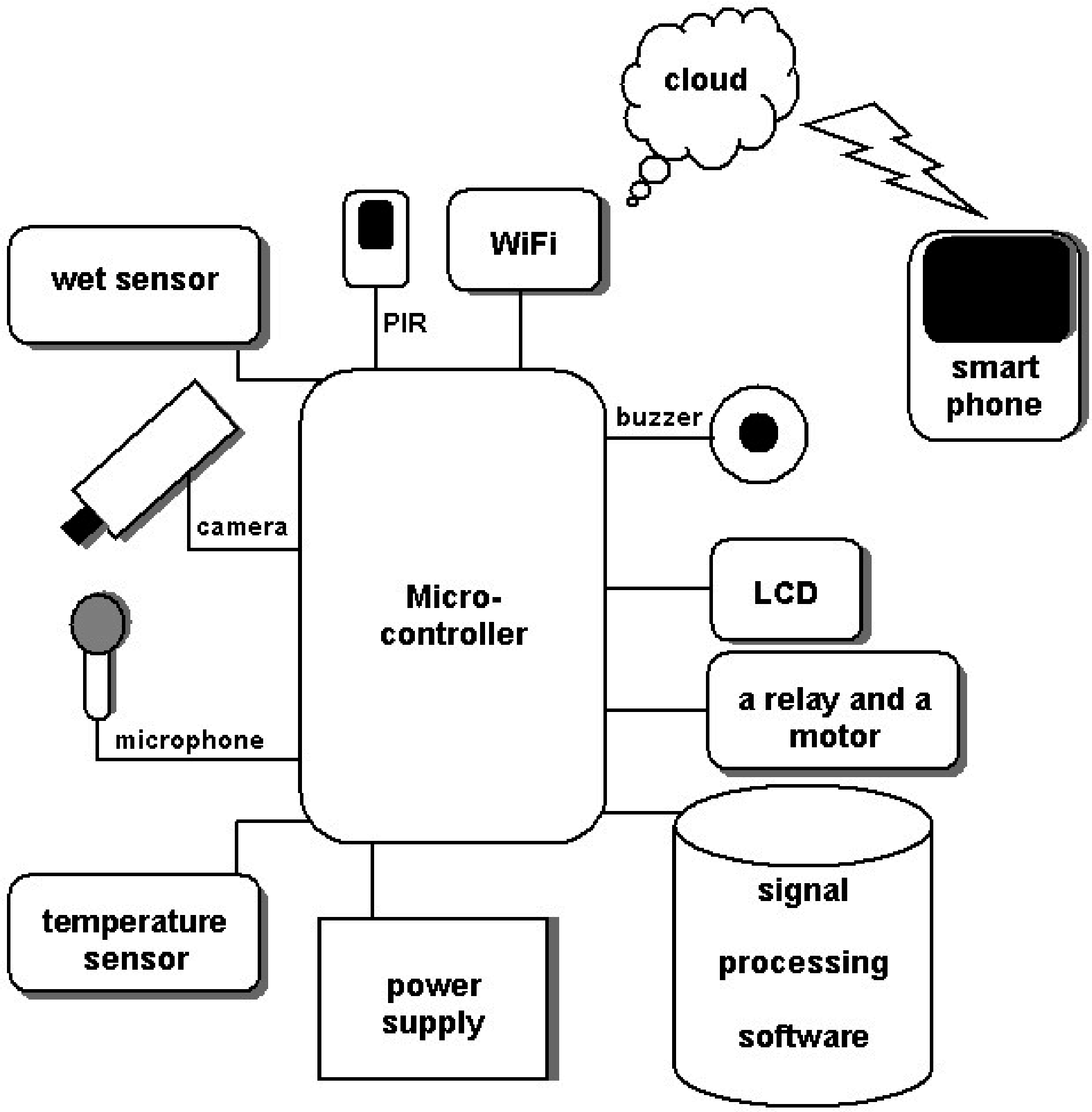

Figure 1. *The principial design of the smart cradle system.*

For example here is an example about the smart cradle system. A smart cradle by (Jadhav et al., 2019) uses weight sensor, noise, wet and temperature sensor, web camera, speaker and 2 motors-one for rotating the toy, the other for swinging the cradle. The weight sensor is used to make sure the baby is still in the cradle. Noise, wet and temperature sensors are used for alerting the parents. Web camera and speaker are used for communication. The system uses Raspberry Pi or Arduino as the main system building component and GSM technology for communicating with the parent's cell phone.

An alphabetical but not a complete list of existing smart cradles

A smart cradle by (Anjikar et al., 2017) detects the baby's crying as an input for swinging the cradle and alarms the parents on 2 occacions: either the mattress becomes wet or the baby cries for long time.

A smart cradle by (Ashraf & Hussain, 2015) uses a PIC16F877A microcontroller, a microphone and a temperature sensor (LM35) as sensing devices. Also the cradle uses a motor for rocking the cradle. The article includes electronic circuits of the cradle system.

A smart cradle by (Bachhav & Chopade, 2018) uses Raspberry Pi, accelerometer sensor (ADXL345), temperature sensor (MAX30205), heartbeat sensor (PPG), speaker and a camera. Also the system is designed to play music and communicate with internet.

A smart cradle by (Dinesh et al., 2015) uses PIC microontroller to drive the DC motor for swinging the cradle and sends out messages to mobile phones.

A smart cradle by (Gare et al., 2019) uses sound sensor for detecting baby's crying, PIR sensor for detecting baby's movements, a wet sensor, 2 temperature sensors (DHT11 and LM35), a GSM module and swinging the cradle.

A smart cradle by (Gawade et al., 2018) includes Atmega16 microcontroller, camera, temperature and wet sensor and an alarm and a relay circuit for rocking the cradle. The article includes electronic circuits.

A smart cradle by (Goyal & Kumar, 2013) uses PIC16F73 microcontroller for running the system, microphone and wet sensor as sensors, an alarm and a motor for rocking the cradle. The whole system is simple but as a notification, one should also notice that the article includes the full electronic circuit of the system.

A smart cradle by (Jabbar et al., 2019) uses NodeMCU ESP8266 WiFi controller, a sound sensor, a temperature sensor, a humidity sensor and a camera. The system also includes a mini fan and a 12V DC motor for rocking the cradle. The software of the system includes Nx Siemens software, Fritzing software, Proteus Stimulation, Arduino IDE software and MQTT Protocol server. The article also includes some software example.

A smart cradle by (Kavitha et al., 2019) uses microphone, moisture sensor, methane sensor, a web camera, GSM module, cloud server and a servo motor. The sensors are used for monitoring the baby and the servo motor is used for swinging the cradle. The main element of the system is a PIC16F73 microcontroller what processes the incoming signals and when necessary, sends out a message with a picture of the baby.

A smart cradle by (Krishna et al., 2019) detects the baby's cry and once the cry has been detected, swings the cradle and plays soft music. Also the system detects if the mattress is wet and does the baby stop crying or not and according to the situation sends SMS to the parents. The baby's cry signal is processed with a fuzzy classifier. The system is based on the usage of Arduino and sensors and actuators connected to it.

A smart cradle by (Nathan et al., 2018) is simple – it uses a wet sensor and a temperature sensor connected to the Arduino Uno for rocking the cradle. What is noticable, is the fact that this article gives an overiew about 22 previously made electronic cradle systems.

A smart cradle by (Natheera et al., 2018) uses Arduino Uno, a wet sensor, a microphone, a camera, a motor, a relay module and ESP8266 WiFi module.

A smart cradle by (Shastry et al., 2017) uses Arduino Uno and Raspberry Pi as signal processing modules, microphone, webcam and FC-37 moisture sensor as sensors, speaker and motor for swinging the cradle. In case of an emergency, the system sends out an e-mail.

A smart cradle by (Srikanth et al., 2018) uses Raspberry Pi 3 microcontroller, wet sensor, a PIR sensor, a camera, a sound sensor and and a temperature sensor for rocking the cradle and sending the SMS to the parents.

A smart cradle by (Srivastava et al., 2019) uses noise sensor, DHT sensor, PIR sensor, WiFi module, Arduino, camera module and a servo motor. The sensors are used for monitoring the baby, Arduino for signal processing, WiFi for communicating with the cloud server and a servor motor for rocking the cradle. Here DHT means a temperature and humidity sensor.

A smart cradle by (Tari et al., 2016) uses camera and microphone as the sensors, WiFi module for communication with parents and 12V engine rocking the cradle. The system uses Arduino Uno as the main module.

A smart cradle by (Tupkar et al., 2020) uses Arduino as the main module, noise sensor for detecting baby's crying, PIR sensor for detecing body movements, DHT sensor, WiFi module and sends data to the cloud server. Here DHT means a temperature and humidity sensor. The system also includes a camera for monitoring and a servo motor for rocking the cradle.

References

A.D. Anjikar et al., 2017

Analysis and Synthesis of Smart BASSINETS for Infants,
International Journal of Advanced Research in Science, Engineering and Technology,
Vol. 4, Issue 3, March 2017,
ISSN: 2350-0328

J. Ashraf & S. Hussain, 2015

Electronic Cradle,
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE),
Vol. 4, Issue 12, December 2015,
ISSN: 2278-909X

S.S. Bachhav & N.B. Chopade, 2018

IoT Based Healthy Baby Cradle System,
IJARIIE-ISSN(O)-2395-4396, Vol. 4, Issue 4, 2018

R. Boomidevi et al., 2015

Monitoring Cardio Respiratory and Gesture Recognition System Using Sensor Pillow System,
International Research Journal of Engineering and Technology (IRJET),
Vol. 2, Issue 08, November-2015, ISSN: 2395-0056

C-T. Chao, et al., 2015

An Arduino –Based Resonant Cradle Design with Infant Cries Recognition,
Sensors 2015, 15, 18934-18949,
ISSN: 1424-8220

R. Dinesh et al., 2015

Analytical Modelling and Design of a Mechatronic Cradle System,
IJSRD- International Journal for Scientific Research & Development,
Vol. 3, Issue 10, 2015, ISSN: 2321-0613

H.S. Gare et al., 2019
IOT Based Smart Cradle System for Baby Monitoring,
International Research Journal of Engineering and Technology (IRJET),
Vol. 6, Issue 10, Oct 2019,
ISSN: 2395-0056

S. Gawade et al., 2018
Automated Baby Cradle,
International Journal of Electronics, Electrical and Computational System(IJEECS),
Vol. 7, Issue 3, March 2018,
ISSN: 2348-117X

M. Goyal & D. Kumar, 2013
Automatic E-Baby Cradle Swing based on Baby Cry,
International Journal of Computer Applications(0975-8887),
Vol. 71, No. 21, June 2013

W.A. Jabbar et al., 2019
IoT-BBMS: Internet of Things-Based Baby Monitoring System for Smart Cradle,
IEEEAccess, Vol. 7, 2019

M.I. Jadhav et al., 2019
Survey Paper on Internet of Things based Smart Baby Cradle,
Recent Trends in Androids and IOS Applications, HBRP Publication,
Vol. 1, Issue 3, 2019, pp. 1-4.

R. Jayaraj et al., 2017
A Review on Detection and Treatment Methods of Sleep Apnea,
Journal of Clinical and Diagnostic Research, 2017, Mar, Vol 11(3), VE01-VE03

R. Kala, 2016
Electronically Equipped Beds Used In Sleep Medicine,
Tallinn University of Technology,
ISBN: 978-9949-83-013-8

S. Kavitha et al., 2019
Smart Infant Cradle System with an Android Application for Baby Monitoring,
International Journal of Engineering Science and Computing,
Vol. 9, Issue 5, May 2019

A. Krishna et al., 2019
Smart Cradle By Using Messaging & Sensing Technology,
International Research Journal of Engineering and Technology (IRJET),
Vol. 6, Issue 5, May 2019, ISSN: 2395-0056

S. Li & C. Chiu, 2018
A Smart Pillow for Health Sensing System Based on Temperature and Humidity Sensors,
Sensors 2018, 18, 3664, DOI:10.3390/s18113664

K.B. Man & M.C. Bae, 2018
Snoring Sound Classification using Efficient Spectral Features and SVM for Smart Pillow,
Journal of the Korea Industrial Information Systems Research, Vol. 23, No. 2,
Apr. 2018, pp. 11-18., ISSN: 1229-3741

I. Natheera et al., 2018
Smart Cradle,
Asian Journal of Applied Science and Technology (AJAST),
Vol. 2, Issue 2, pp. 291-300, April-June 2018,
ISSN: 2456-883X

S.S. Nathan et al., 2018
Survey on Digital Age – Smarter Cradle System for Enchanced Parenting,
International Journal of Applied Engineering Research,
Vol. 13, No 10, pp. 8187-8193,
ISSN: 0973-4562

S.P. Shastry, 2017
Instrumentation Sensors Based Infant Safety Smart Cradle,
Int. Conf. On Signal, Image Processing & Automation, ICSIPCA

Sakila et al., 2018
Automated Smart Pillow for all Age Group,
International Journal of Innovative Science and Research Technology,
Vol. 3, Issue 10, October 2018,
ISSN: 2456-2165

S. Srikanth et al., 2018
Smart Baby Cradle System,
International Journal of Advances in Scientific Research and Engineering (IJASRE),
Vol. 4, Issue 3, March 2018,
ISSN: 2454-8006

A. Srivastava et al., 2019
Smart Cradle System for Child Monitoring using IoT,
International Journal of Innovative Technology and Exploring Engineering (IJITEE),
Vol. 8, Issue 9, July 2019,
ISSN: 2278-3075

S.P. Patil., 2018
Smart Pillow - The Future of Sleep & Talk Technology,
International Journal of Engineering Science Invention (IJESI),
Vol. 7, Issue 3, Ver 2, March 2018, pp. 01-06,
ISSN: 2319-6734

M. Tari et al., 2016
Smart Crib Application Developed Using Smart Phone and Embedded System,
Proceedings of 2nd International Conference on Networking and Computer Application,
13-14th July, 2016, Bangkok,
ISBN: 9788193137352

A.B. Tupkar et al., 2020
Development of IoT Based Smart Baby Cradle,
International Advanced Research Journal in Science, Engineering and Technology,
Vol. 7, Issue 1, January 2020,
ISSN: 2393-8021

V. Verhaert, 2011
Ergonomic analysis of integrated bed measurements: towards smart sleep systems,
Doctor in Engineering thesis.
Katholike Universitet Leuven- Faculty of Engineering,
ISBN: 978-94-6018-450-5

R. Xie et al., 2018
Design and Manufacturing of Variable Stiffness Mattress,
46th SME North American Manufacturing Research Conference, NAMRC 46,
Texas, USA,
Procedia Manufacturing 26(2018), pp. 132-139

L. Rachakonda et al., 2018
Smart-Pillow: A Stress Monitoring System through the IoT
Publications_Conferences/2018/Mohanty_IEEE_MetroCon-2018_Smart-Pillow_Abstract.pdf

Huijia Health Technology
http://www.huijiahealth.com.tw/, 2019

3.4 INCUBATORS

3.4.1 INTRODUCTION

The term baby monitoring can be understood in many different ways. Usually people think that baby monitoring is something what happens at home. However, situations can be more complicated and certainly babys need monitoring also in the hospitals and in some cases, being in a controlled environment. This leads us to the usage of the incubators. The incubators have two tasks to perform – keep the baby in a thermally controlled environment and monitor the baby's health status. Additionally, it is also good when the incubator warns us about the child stealing attempt. Therefore the incubator can also have alarms. Before going into more details a brief historical overview is given.

The first attempts to build an incubator date back to 1880 when the French obstetrician Stephane Tarnier built a device what housed several infants in an environment which had hot water reservoir on top of the infants as a heating device. Although this new "device" had nothing what could be described as extreme novelty, it opened a way for others. The first critisisms about the incubator appeared in 1883 in an article written by German obstetrician Carl Crede. It has to be said, that this was really fast response in a world without internet. This lead into great discussions about French infants mortility and so in 1893 the Maternite Hospital in Paris with incubator wards was opened. In 1900 Pierre Constant Budin published a book – "Le Nourrisson (The Nursling)" and became a great authority of the premature infants. In 1890s in Nice, France a man named Alexandre Lion designed more complicated incubator than that of the Tarnier's but because his device was so expensive, it remained without attention in France but araised interest in the USA where people started with the incubator shows. In 1914 Julius Hess in Chicago designed an incubator with an "electrical heated bed" (Baker, 2000). One of the eraliest incubators using electrical heating is described in an article published in 1920 (Northrop, 1920). The first modern incubators appeared after World War 2 (Magnarelli, 2006). The first neonatal intensive care units were formed in the 1950s (Magnarelli, 2006).

Considering the design principles, the incubators can be classified into 2 big classes – open incubators with radiant warmer and closed incubators (Hull & Wheldon, 1986). Quite often open and closed incubators use the same sensors for monitoring but the question is how to overcome heat loss problems.

A typical modern incubator has sensors monitoring the baby's health status (SpO_2, ECG, temperature), sensors monitoring the environment (temperature, O_2 flow, humidity, door openings), a heating device, an alarm and e-mail/SMS messaging. One such kind of incubator is shown in an article by (Subramanian et al., 2019). Also one can say that within years the complexity of the whole picture has increased. Not only are the devices (incubators) more complex, but also more devices are integrated into one whole system. One such example is a web-based remote monitoring of the infant inside the incubators in the ICU (Shin et al., 2003).

3.4.2 THE DESIGN PRINCIPLES OF SOME EXISTING INCUBATORS

There are many articles describing the design of a microcontroller based incubator. Usually the articles describe the sensors used and the data transfer and signal processing. However, there are also interesting aspects like in an article by (Costa et al., 2009) what describes the humidity control system of the baby incubator. There is also an interesting article written by (Sreenath et al., 2012) what gives a lot of information about the product specification related problems and offers 5 different product designs. However, what is sad about these things, is that all these articles have a lot of overlaping information and there are no clear sub-classes. Because of that a brief list of existing devices is mentioned but the list is not complete and certainly it will grow longer in the future. Another aspect what should be mentioned is that although the following articles describe the same problem, the aspects mentioned are very different and sometimes this may cause a lot of confusion. For example let's take the articles written by (Ishak et al., 2017) and (Theopaga et al., 2014). Both articles have been written about the same time and describe the usage of almost same components but with different aspects and levels of difficulty.

An article written by (Ishak et al., 2017) describes the usage of Arduino Uno microcontroller, optic pulse rate sensor, humidity sensor and a buzzer.

An article written by (Theopaga et al., 2014) describes the design of the PID control based incubator. Here PID – Proportianal-Integral-Derivative. The system is based on Ziegler-Nichols 1st tuning method by giving the open-loop system an unit-step input. The hardware consists of the following elements: Arduino Uno, SHT-11 temperature and humidity senor, NTC temperature sensor, LCD screen, a heating element and a buzzer. The PID aspect is further advanced with the usage of Artificial Neural Networks (ANN) in an article written by (Bansal et al., 2015).

A system built by (Shin et al., 2003) uses measuring modules inside the incubators and measuring modules are connected to the web-server via RS-485 serial interface. The measurement modules measure temperature and humidity and do some signal processing with a PIC16C73 microcontroller. The measurement module stores data in FIFO memory (32 kB), storing temperature and humidity data with rate 8 bits at 15 s intervals.

A system built by (Zaylaa et al., 2018) uses 3 D simulation in order to print a small 3 D baby incubator which measures heart rate (HR), temperature and SpO2 and for therapeutic purpouses applies heating and oxygen relase. The system uses Atmega328 microcontroller as the main driving unit and Arduino Micro as the additional microcontroller. Also there is a quite a similiar system built by (Shaib et al., 2017) what is a portable incubator, measuring heart rate (HR), temperature, oxygen saturation (SpO2) and displays the data on LCD screen and also on mobile application or web server.

A system designed by (Dive & Kulkarni, 2013) uses DSPIC microcontroller, a microphone for audio monitoring, light sensing, door opening sensor, a temperature sensor, alarm and a speaker in the control room. An article by (Kumar & Suryakala, 2016) describes the usage of Arduino Uno, thermistor.

There is also an article describing thermodynamic mathematical model of premature infants placed into the incubator (Feki et al., 2017). Here spatially lumped mathematical model using the laws of conservation of heat and mass is used. The infant incubator is sub-divided into 6 homogenous compartments: the neonate core, skin, incubator air space, heater, wall and mattress. The article describes the equations in a detailed way.

A system built by (Sowmiya et al., 2018) uses ESP8266 as the main node, a M212 pulse sensor, a light sensor, temperature and humidity sensor (DHT-11), a LPG gas sensor (MQ6), WiFi for data transfer and Ubidots cloud software. This article also points out that in the future, the incubators should also measure EMF exposure. Another similiar device is described in an article by (Sivamani et al., 2018). In an article written by (Shakunthala, 2018) same sensors and software is used but also mentions the usage of the solenoid valve for controlling the gas flow.

References

J.P. Baker, 2000
The Incubator and the Medical Discovery of the Premature Infant,
Journal of Perinatology, 2000, 5, pp. 321-328

H. Bansal et al., 2015
Controlling of Temperature and Humidity for an Infant Incubator Using Microcontroller,
International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4., Issue 6, June 2015
ISSN: 2278-8875

E.J.L. Costa et al., 2009
Humidity Control System In Newborn Incubator,
XIX IMEKO World Congress, Fundamental and Applied Metrology,
September 6-11, 2009, Lisbon, Portugal

K. Dive & G. Kulkarni, 2013
Design of Embedded Device for Incubator for the Monitoring of Infants,
International Journal of Advanced Research in Computer Science and Software Engineering, Vol. 3, Issue 11, November 2013,
ISSN: 2277-128X

E. Feki et al., 2017
GPC Temperature Control of A Simulation Model Infant-Incubator and Practice with Arduino Board,
International Journal of Advanced Computer Science and Applications,
Vol. 8, No. 6, 2017

D. Hull & A. Wheldon, 1986
Open or closed incubators,
Archives of Disease in Childhood, 1986, 61, pp. 108-109

D.N.F.M. Ishak et al., 2017
Arduino Based Infant Monitoring System,
International Research and Innovation Summit (IRIS 2017)
IOP Conf. Series: Materials Science and Engineering, 226, 2017

Kumar & Suryakala, 2016
Temperature Control and Monitoring of Incubators Using IoT
International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE), Vol. 22 Issue 1 – MAY 2016.
ISSN: 0976-1353

F. Magnarelli, 2006
Infant Incubators,
Biomedical Instrumentation & Technology, May/June 2006

J.H. Northrop, 1920
A device for regulating the temperature of incubators either above or below room temperature,
The Journal of General Physiology

M. Shaib et al., 2017
Advanced Portable Preterm Baby Incubator,
2017 Fourth International Conference on Advances in Biomedical Engineering (ICABME)
IEEE, 2017

M. Shakunthala et al., 2018
Neonatal Healthcare Monitoring in Incubator Using IoT,
International Journal of Electrical, Electronics and Data Communication,
Vol. 6, Issue 6, June 2018,
ISSN: 2321-2950

D.I. Shin et al., 2003
Web-based remote monitoring of infant incubators in the ICU,
International Journal of Medical Informatics, 2003, 71, pp. 151-156

D. Sivamani et al., 2018
Smart Incubator using Internet of Things,
International Journal for Modern Trends in Science and Technology,
Vol. 4, Issue 9, September 2018,
ISSN: 2455-3778

S. Sowmiya et al., 2018
Monitoring of Incubator using IoT,
International Research Journal of Engineering and Technology (IRJET),
Vol. 5, Issue 4, April 2018,
ISSN: 2395-0056

S.N. Sreenath et al., 2012
Design of an Infant Incubator for Cost Reduction and Improved Usability for Indian Health Care Centers,
Sastech Journal, Vol. 11, Issue 2, Sep 2012

M. Subramanian et al., 2019
Security And Health Monitoring System Of The Baby In Incubator,
International Journal of Engineering and Advanced Technology (IJEAT),
Vol. 8, Issue 6, August 2019
ISSN: 2249-8958

A.K. Theopaga et al., 2014
Design and Implementation of PID Control Based Baby Incubator,
Journal of Theoretical and Applied Information Technology,
Vol. 70, No. 1, 10 December 2014
E-ISSN: 1817-3195

A.J. Zaylaa et al., 2018
A Handy Preterm Infant Incubator for Providing Intensive Care: Simulation, 3D Printed
Prototype, and Evaluation
Journal of Healthcare Engineering, Volume 2018, Article ID 8937985, 14 pages

3.5 WIRELESS BODY AREA NETWORKS, WBANS, THE VESTS

3.5.1 INTRODUCTION

3.5.2 WBAN BABY MONITORS

3.5.1 INTRODUCTION

The Body Area Networks (BAN) and later Wireless Body Area Networks (WBAN) have been around for long time. For example one article references to the Body Area Network (BAN) developed in 1976 (Navale et al., 2014). Today there are many articles what describe the overview of the BANs, their arhitecture, applications and other related issues. This sub-chapter mentions 3 articles (Arefin et al., 2017, Felisberto et al., 2012, Singla et al., 2016) describing the overview of BANs based on the principles used for the description of the architecture but the list is not complete.

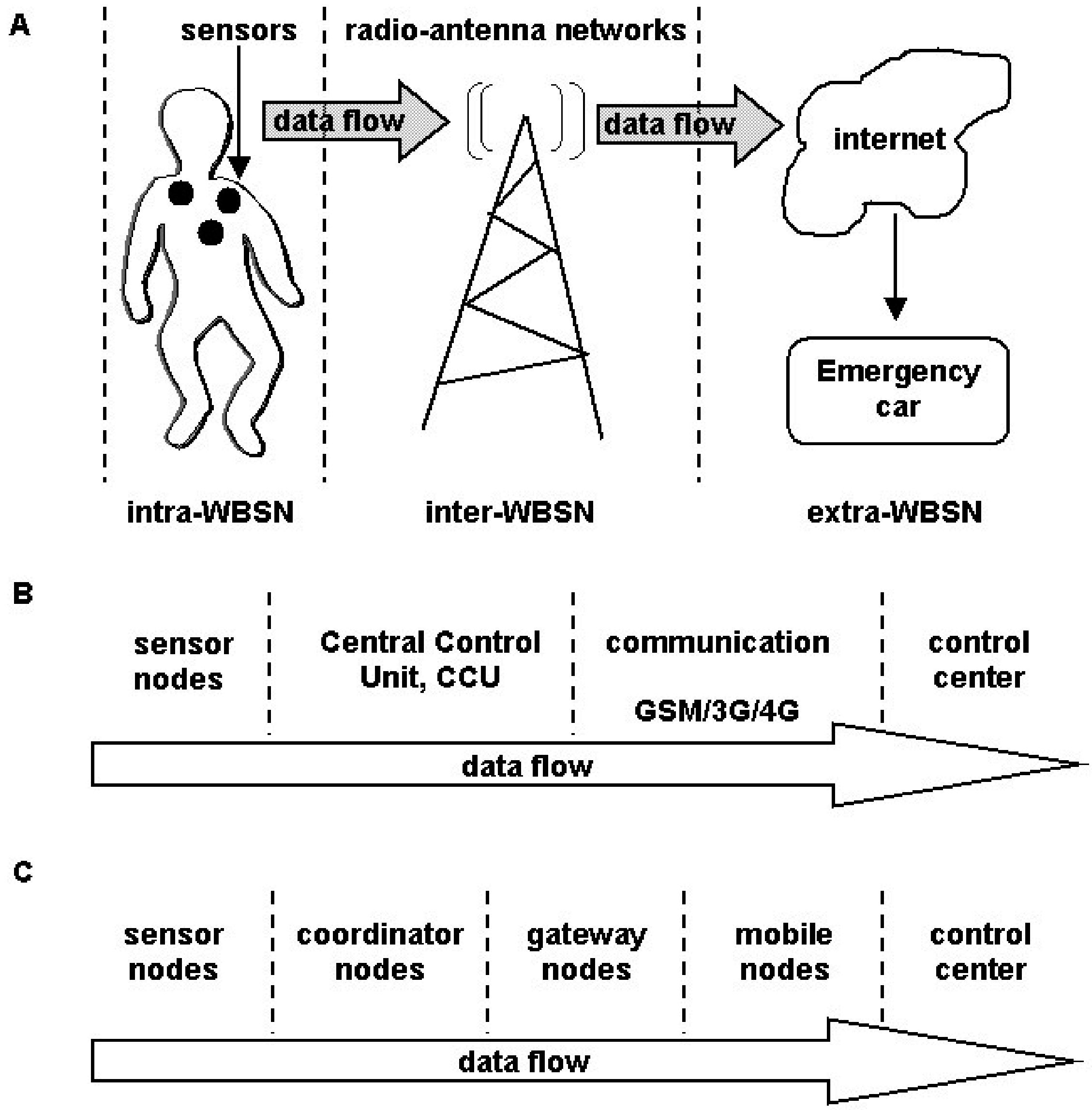

Figure 1. *The architectual design of the BAN / WBAN system.*

The Figure 1 consists of 3 sub-figures named A, B and C. The names are used as following:

- A – the architecture of the WBAN system according to Singla et al.
- B – the architecture of the WBAN system according to Arefin et al.
- C – the architecture of the WBAN system according to Felisberto et al.

The architecture of the WBAN system according to Singla et al. (A) divides the system into 3 big compartments: the intra-, inter- and extra-WBSN. The intra-WBSN refers to the part of the system where sensors are connected to the person. The inter-WBSN refers to the radio-networks used to trasnfer the data. The extra-WBSN refers to the internet and devices connected to it and also the possibility that the emergency car receives data over the internet.

The architecture of the WBAN system according to Arefin et al. (B) divides the system into 4 big compartments: the Sensor Nodes, Central Control Unit, Communication Unit and the Control Center. The Sensor Nodes according to Arefin et al. can be seen as part of the intra-WBSN according to Singla and colleagues. Also the Central Control Unit can sometimes seen as a part of the intra-WBSN system. The Communication Unit according to Arefin and colleagues has some overlappings with the inter-WBSN according to Singla et al. The control center according to Arefin et al means something bigger than just a emergency car.

The architecture of the WBAN system according to Felisberto et al. (C) divides the system into 5 big compartments and therefore it is more detailed than the systems described as A and B. Here the big difference is that instead of using “Communication Unit” it uses 2 nodes: the gateway node and the mobile node. The Cordinator Node can be seen as a Central Control Unit (B).

The interested reader certainly notices that the BAN / WBAN systems consist of sensors connected to the subject under the study, sensor data processing unit, communication nodes, internet and internet-connected devices and the control center. However, there is one serious aspect to be considered, namely there are no standards how to design a BAN / WBAN system and therefore many different components have been used making the whole picture quite fuzzy.

The standards used (Singla et al., 2016, Arefin et al., 2017):

- IEEE, ISO, Bluetooth SIG, ASTM
- WLAN, WiFi, GSM, 3G, 4G and WPAN.

The articles refer to many commonly known aspects like wearability, reliability, security and so on. However, what makes things things difficult is that by now, the WBAN systems are not only systems using only wearable sensors but also implantable devices.

The wireless technologies make our lives much easier but are also dangerous because of the RF-smog. In short notice one can understand that TV sets, PCs, microwave owens, cellural phones and many more devices cause a lot of RF-smog. Although every single device by itself is not dangerous, the summation of all the devices RF-smog in a small area like a flat and in expenditure of long time (years), the result can be dangerous. Therefore it is important to track the RF-smog of the WBAN system (Hou et al., 2013).

In the design of the WBAN system, it is also important to consider the security and privacy aspects (Malik et al., 2018). The following aspects should be taken into consideration: data confidentiality, scalability, data integrity, data authentity, data availability, data security, encryption and data privacy (Malik et al., 2018).

medical WBAN

Medical wireless body area networks have been described in many different overview articles, for example by (Navale et al., 2014, Freitas & Azevedo, 2016, Ullah et al., 2010, Koydemir & Ozcan, 2018). The interested reader certainly finds that most of the medical WBAN related articles describe sensing and monitoring but the topic is not so primitive and there are articles what describe actuators, alarming devices and alerts like SMS (Kumar et al., 2016). According to (Sindhu et al., 2016) the design considerations can be summarized as:

- Unobtrusive, small and lightweight
- Reliable
- Robust
- Energy efficient / minimal power dissipation
- Frequency dependant. The higher the frequency, the higher it's absorption into the tissue.

As mentioned by (Ullah et al., 2010), the medical WBAN uses Wireless Telemetry Services (WMTS), unlincensed Industrial Scientific and Medical (ISM), ultra-wideband (UWB) and Medical Implant Communications Service Bands (MICS), 14 MHz bandwidth, 2.4 GHZ ISM and 402-405 MHz MICS band. The article mentions the body's electrical properties in the 100-900 MHz range. Also the article takes into account the dipole antenna, loop antenna and patch antenna aspects. It is interesting to notice that the article includes a table what describes in-body and out-body sensor network's data rates, duty cycles and power consumption aspects.

An article written by (Freitas & Azevedo, 2016) mentions the WBAN applications used in healthcare and the differencies between wireless sensor networks (WSN) and wireless body area networks (WBAN).

An article written by (Koydemir & Ozcan, 2018) gives a good overview about wearable and implantable biomedical devices, the vital signs measured, the sensor used and the materials used. This also includes the smart textiles and stretchable electronics.

While talking about specific WBAN related articles, the most thoroughly searched topic is heart rate (HR) monitoring (Thwe & Tun, 2015, Venugopal & Kumar, 2013).

3.5.2 WBAN BABY MONITORS

There are many articles what describe WBAN Baby Monitors and considering the architectural aspect, these look similar like the WBANs designed for the adults. For example the signals to be measured are the same: temperature, heart rate, breathing rate and body position. Also WBAN Baby Monitors include the processing unit, the signal transmission unit and software what displays the results in some kind of control center. There is one article what describes the comparision of different wireless technologies used for child health monitoring (ur-Rehman, 2018). The article includes the following wireless technologies: WiFi, Bluetooth, ZigBee, 6LoWPAN, RFID and LoRaWAN. However, one should always keep an eye on vital signs to be measured and sensing principles and related tables, just like (Zhu et al., 2015). The same article also mentions ECG measurement techniques and smart textile electrodes, essential components of the WBAN Baby Monitors. The following gives a brief literature overview. The first 2 articles mentioned are the most specific baby-related WBAN devices (Bouwstra et al., 2009, Linti et al., 2006). The other following articles also describe baby related WBAN devices but not so specifically.

A Brief Literature Overview of WBAN Baby Monitors

There is one special article what describes the design of a smart jacket with textile ECG electrodes (Bouwstra et al., 2009). What is interesting is the fact that the system measures the ECG lead electrodes and always selects the strongest electrode. This is of great help when some electrode becomes disconnected for some reason. The system also includes notch, high pass and low pass filters in order to remove any unwanted noise, higher harmonies and 50 Hz component.

There is a special article what describes the design of the sensory baby vest (Linti et al., 2006). The vest measures respiration rate, heart rate, temperature and humidity. The system uses micro-wires (AWG-36) to collect the data from the sensors. The respiration signal is measured with the usage of resistive strain sensors. The ECG signal is collected with the usage of the dry electrodes placed left and right of the breast and belly. The humidity sensor is used to detect sweating and it consists of 2 pairs of ECG-electrode measure sensors what measure resistance of the textile fibers of the vest (backside). Temperature sensor consists of 2 NTC thermistors. The software used is LabView 5.0.

An article written by (Hiware & Tete, 2017) describes infant monitoring with smart wearable system. The primary cause mentioned is the ability to detect possible Sudden Infant Death Syndrome (SIDS) with the usage of heart rate (HR) sensor, Breathing Rate (BR) sensor and position sensor. The data transmission is through WiFi. (Patil & Mhetre, 2014) describe intelligent baby monitoring system what measures temperature (LM35), pulse rate(IR), moisture and motion (ADXL335). The measurands are transferred through GSM and displayed on LCD. The system also includes a buzzer. The data is processed with PIC 18f4520 8-bit microcontroller and the software is written in embedded C.

An article written by (Oshin et al., 2017) describes infant monitoring in order to detect Sudden Infant Death Syndrome (SIDS). The system uses temperature and heart rate sensors and Arduino Nano as the main components. For data transmission WiFi is used.

An article written by (Venkataramani et al., 2015) describes infant monitoring with the usage of Arduino Uno microcontroller, CC33000 WiFi shield, LM35 temperature sensor, IR-pulse sensor and LSM303D accelerometer.

An article written by (Vora et al., 2017) describes infant monitor using heart beat and respiration rate detection and RFID tags! Heart beat monitoring is conducted with the usage of the ECG contact electrodes. For respiration rate measurement strain gauge is used.

References

T. Arefin et al., 2017
Wireless Body Area Network: An Overview and Various Applications,
Journal of Computer and Communications, 2017, 5, pp. 53-64
doi: 10.4236/jcc.2017.57006
ISSN: 2327-5227

S. Bouwstra et al., 2009
Smart Jacket for Neonatal Monitoring with Wearable Sensors,
2009 Body Sensor Networks, IEEE,
doi: 10.1109/P3644.39

F. Felisberto et al., 2012
Unobstructive Body Area Networks (BAN) for Efficient Movement Monitoring,
Sensors, 12, 2012, 12473-12488
doi:10.3390/s120912473
ISSN: 1424-8220

E. Freitas & A. Azevedo, 2016
Wireless Biomedical Sensor Networks: The Technology,
Proceedings of the 2nd World Congress on Electrical Engineering and Computer Systems and Science (EECSS'16),
Budapest, Hungary, August 16-17, 2016,
Paper No ICBES 134,
doi: 10.11159/icbes16.134

Hiware & A.D. Tete, 2017
Sudden Infant Death Monitoring Using Smart Wearable System,
International Journal of Science, Engineering and Technology Research,
Vol. 6, Issue 2, February 2017,
ISSN: 2278-7798

Y. Hou et al., 2013
Surviving the RF Smog: Making Body Area Networks Robust to Cross-Technology Interference,
2013 10th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON)
Doi: 10.1109/SAHCN.2013.6645005

H.C. Koydemir & A. Ozcan, 2018
Wearable and Implantable Sensors for Biomedical Applications,
Annual Review of Analytical Chemistry, 2018

R. Kumar et al., 2016
Health Monitoring In Remote Areas Using WBAN,
International Journal of Advanced Computational Engineering and Networking,
Vol. 4, Issue 3, March 2016,
ISSN: 2320-2106

Linti et al., 2006
Proceedings of the International Workshop on Wearable and Implantable Body Sensor Networks (BSN'06), IEEE
doi: 10.1109/BSN.2006.49

M. S. A. Malik et al., 2018
Wireless Body Area Network Security and Privacy Issue in E-Healthcare,
International Journal of Advanced Computer Science and Applications,
Vol. 9, No. 4, 2018

M.C. Navale et al., 2014
A Survey on Body Area Network in Healthcare System,
Multidisciplinary Journal of Research in Engineering and Technology,
Vol. 1, Issue 2, pp. 143-151
ISSN: 2348-6953

O. Oshin et al., 2017
Development of a Wearable for Remote Health Monitoring in Infants,
Proceedings of the World Congress on Engineering and Computer Science,
WCES 2017,
October 25-27, 2017, San Francisco, USA,
ISSN: 2078-0966

S.P. Patil & M.R. Mhetre, 2014
Intelligent Baby Monitoring System,
ITSI Transactions on Electrical and Electronics Engineering,
Vol. 2, Issue 1, 2014,
ISSN: 2320-8945

A-ur-Rehman et al., 2018
Wireless Body Area Networks for Child Healthcare Monitoring: A Review,
2018, IEEE

S. Sindhu et al., 2016
A Review on Wireless Body Area Network (WBAN) for Health Monitoring System: Implementation Protocols,
Communications on Applied Electronics (CAE), USA,
Vol. 4, No. 7, March 2016,
ISSN: 2394-4714

S. Singla et al., 2016
A Review Paper on Wireless Body Area Network for Health Care Applications,
International Journal of Computer Science and Mobile Computing,
Vol. 5, Issue 10, October 2016, pp. 1-11.
ISSN: 2320-088X

H.M. Thwe & H.M.Tun, 2015
Patient Health Monitoring Using Wireless Body Area Network,
International Journal of Scientific & Technology Research,
Vol. 4, Issue 6, June 2015,
ISSN: 2277-8616

S. Ullah et al., 2010
A Review of Wireless Body Area Networks for Medical Applications
International Journal of Communications, Network and System Sciences,
Vol. 2, No. 8, pp. 797-803

K. Venupogal & A.Kumar, 2013
Centralized Heart Rate Monitoring and Automated Message Alert System using WBAN,
International Journal of Scientific and Research Publications,
Vol. 3, Issue 9, September 2013,
ISSN: 2250-3153

D. Venkatarmani et al., 2015
Infant monitoring using wearable computing,
International Journal of Engineering and Technical Research,
Vol. 3, Issue 11, November 2015,
ISSN: 2321-0869

S.A. Vora et al., 2017
On Implementing an Unconventional Infant Vital Signs Monitor with Passive RFID Tags,
2017 IEEE International Conference on RFID

Z. Zhu et al., 2015
Wearable Sensor Systems for Infants,
Sensors 2015, 15, pp. 3721-3749,
doi: 10.3390/s150203721
ISSN: 1424-8220

CHAPTER 4

THE SIGNALS OF THE ELECTRONIC BABY MONITORS

4.1 THE MOST COMMON CHARACTERISTICS OF THE BIOSIGNALS

4.1.1. INTRODUCTION

There are many books and articles what describe the characteristics of the biosignals very well. For example, the person interested in electronics can find a lot of information about the characteristics of the signals from (Horowitz and Hill, 2001, Geddes and Baker, 1989). The generation of the human bio-signal can be understood by reading medical books (Metting, 1976, Schmidt and Thews, 1997, Kärner, 1997).

4.1.2. THE CHARACTERISTICS OF THE BIOSIGNALS

Describing the measurable signal is always a big problem. There are many aspects to be considered and there is no one and only acceptable solution. Therefore the choice of the characteristics of the biosignals is a philosophical problem. For example, one has to know what kind of components of the signal carry information and what kind of components of the signal carry noise and distortion. Also, dependant of the situation, the same signal (for example EMG) can be considered as signal or noise (Togawa, 2011). Within this sub-chapter only most commonly used characteristics of the biosignals are described. The interested reader can find additional information from various books (Webster, 2004, Geddes and Baker, 1989) and articles (Rahul et al., 2019, Sentürk et al., 2019).

4.1.3. SIGNAL TYPES

There are many ways how to classify signals. Most common ways to classify signals is to divide them into classes according to the signal shape (pattern) and frequency spectrum.

Both classes have their pro's and cons. However, this is not the only way how to classify the signals. Sometimes it is much wiser to classify the signals according to some other kind of principle, for example according to the signal generation method, measurement method, type of sensor and according to the noise spectrum. Also, one has to know what are typical, maximum and minimum values of the signal. This is important in order to understand if there is something wrong with the patient or measurement system, if everything is according to the security standards or anything else. Some signals have been classified according to very strong requirements. For example, the ECG signal has to be in the range of 0.5 mV to 5.0 mV, combined with a DC component +/- 300 mV (Bosch & Hartmann, 2003). The following lists some most fundamental questions.

Origin of the signal	Signal processing
• What is the amplitude range ?	• amplification
• What is the frequency response ?	• filtering
• Is the signal periodic or non-periodic ?	• classification
• Does the signal have any specific pattern ?	• storage
• Does the signal include any kind of artefacts or noise ?	• artefact removal (for example baseline wander)

***Figure 1**. The origin of the signal.*

4.1.4. SIGNALS AND NOISE

We all know that signals are important but noise is always present, even then we don't want it. The question is how does the noise look like – how big in amplitude and how does the noise spectrum look like. The main question in dealing with noises is how big is the noise in comparision to the signal and does the noise have overlappings with the signal in the spectrum. There are many electronics books (Horowitz and Hill, 2001, Heinrichen, 1996) and articles (Belo et al., 2017, James and Hesse, 2005) what describe this phenomena in detail. Sometimes it may be useful to search for mathematics books (Glover and Mitchell, 2002, Rowe, 1997) because they describe different distributions in detail, in equations and graphs. Probably the most used tool for desrcibing the signal and noise is the signal to noise ratio (**SNR**), described in logarithms and decibels (usually in dB).

The Signal to Noise Ratio, the decibells and logarithms

By definition $dB = 20 \log_{10}(A_2/A_1)$ **Equation 1**

Where A_1 and A_2 describe the amplitudes of the signals. In a more detailed way we can think of A_2 as Signal and A_1 as of Noise. In that case **Equation 1** describes the Signal to Noise ratio (**SNR**) and can be used for describing different signals or the ability of the amplifier or filter to reject noise – when we have Common Mode Rejection Ratio (**CMRR**). The **CMRR** remains stable inside the low frequency spectrum but is not stable inside the high frequency spectrum (MT-042). Sometimes scientists re-define the calculation of the **CMRR** (Koide, 1997).

However, sometimes it is more useful to compare power levels and when:

$dB = 10 \log_{10}(P_2/P_1)$ **Equation 2**

Where P_1 and P_2 describe the power of the signal.

Usually the scientists and engineers have to deal with many signals and when it is wise to describe the signals not only on graphs but also on tables which include the signal's amplitude or power in relation to the decibels. This can be useful when we have a complex system which consists of multiple parts and each part of the system amplifies/attenuates the signal in a different manner. Because the decibels can be summed as:

dB(1) + dB(2) + dB(3) ..... = Sum of different signals, **Equation 3**

where dB(1) is the dB value of Signal 1,
dB(2) is the dB value of Signal 2, etc.

we can add up all the dB values and calculate the total output of the system. Also, the same summing can be used in a “reverse” manner. For example, when we know how big is the output of the system but want to know “how big” the components have to be. A good engineer or scientist is not only able to compose something but also able to de-compose the system or signal into smaller units.

4.1.5. TYPES OF NOISE

As described eariler, the noise is always present. In order to better understand the behaviour of the noise, it is useful to classify the noise according to the generation method (thermal, 1/f, power line, baseline wandering, artefact) or according to the shape of the spectrum. The noise spectrum’s shape is important when the measurable signal is chaotic in nature, semi-periodic and there is no single “main frequency”. This is extremly true in case of measuring the EEG signals.

Thermal noise aka Johnson / Nyquist noise, white noise

Thermal noise is always present. It is not a problem when designing the most common type of a radio but it can be a big problem when you have to amplify very small signals. The more you amplify the signal, the more you amplify the noise. So, one has to ask, if there is a possibility to use any kind of noise cancellation methods. The noise cancellation methods exist for long time, usually it is the cost or complexity of the design what limit the usage of it. The good thing with thermal noise is, that it is well described – the noise is random and distributed uniformly over the frequency spectrum. The Johnson noise is described by **Equation 4**. This can be useful when using resistors (Horowitz and Hill, 2001).

V(noise, RMS) = sqrt(4kTRB) **Equation 4**

Where:

V(noise, RMS) is the root-mean-square voltage level of the circuit there the resistor is used

k – Boltzmann constant
T – absolute temperature in degrees of Kelvin
R – resistance in ohms
B – bandwidth in hertz (Hz)
1/ f noise aka flicker noise, pink noise

This noise has 1/ f spectrum (equal power per decade of frequency) and is called as pink noise (Horowitz and Hill, 2001, Togawa, 2011). In case of designing an electronics device, the 1/ f noise is usually clear. However, when dealing with physiological signals, the 1 / f noise has to be considered as a signal, not as a source of noise (Togawa, 2011).

power line hum

It is easy to recognise the power line hum because it has the frequency of the power line (usually 50 Hz) and it is always present when the device is connected to the mains and disappears when the device is disconnected from the mains. Sometimes the power line hum can be very big and distort all the measurable signals. If possible, it would be a good idea to use both – analog and digital filters inside the same device to remove the power line hum. By using both possibilities, it is possible to design more effective and more flexible filter. Using only analog filters may remove parts of the valuable signal and using only digital filtering can cause to much computing to the microcontroller. When both filters are in usage, one helps the other.

baseline wandering

This type of noise is present when the signal has the ability to remain in the normal shape but the amplitude by itself wanders up and down. This type of “noise” can be seen for example in the ECG recordings. The cause of the baseline wandering in the ECG signal is either a movement induced artefact or breathing (Gupta et al., 2015). Sometimes the baseline wandering may be caused because of loose electrodes. The baseline wandering disrupts the automatic ECG detection systems and makes it almost impossible to automatically detect ECG’s ST-segment (Lenis et al., 2017). Figure 2 displays a handdrawn picture about ECG signal with baseline wandering. This picture is not exact but it shows the signal alterating trend caused by baseline wandering.

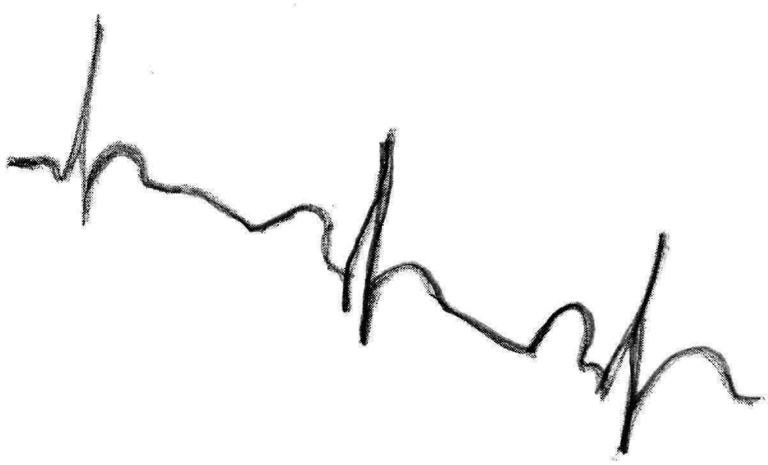

***Figure 2**. ECG signal with baseline wandering.*

The same article (Lenis et al., 2017) suggests 5 baseline wandering removal techniques: Butterworth filtering, moving median and subtraction, wavelet based cancellation, spline approximation and wavelet based high-pass filtering.

artefacts

Almost everything can be a artefact, so there is no single definition for it and because of it is always wise to keep in mind what is the situation(context) and what we are looking for. The most awful enemy we have to face with is our brain. I mean, while diagnosing daytime ECG signals we think one way and while diagnosing night-time ECG signals we think in a different manner. Therefore we may miss a lot of important information.

There are articles what describe the ECG artefacts (Rasheed, 2017, Perez-Riera, 2017). Sometimes we may think that electrodes are placed normally, the ECG-recording device works but still there is something wrong with the signal? It may be that the patient has cardiac pacemaker installed. So it is always wise to ask the patient if he/she has a pacemaker installed before the measurement session begins.

There are also good articles what describe well the movement induced artefacts in wearable ECG recordings (An and Stylios, 2020) and in (Imtiaz et al., 2016).

4.1.6. SOME SIGNAL CHARACTERS

Amplitude

Every signal has amplitude but the amplitude can become distorted by the usage of the filters or circuits inside the device acting as filters. The amplitude distortion topic is briefly covered in a book by (Geddes and Baker, 1989). More amplitude distortion related information can be found from electronics-related books and articles.

Phase

Usually engineers and even scientists don't think about phase measurements because knowing about the signal's time-pattern or some simple frequency pattern is good enough. However, phase measurements become important when you want to do exact measuremnts, having timing stamps. According to (Geddes and Baker, 1989), the first phase distortion measurements in biomedical engineering were done in 1959 by Saunders and Jell (Saunders and Jell, 1959, Time distortion in electroencephalograph amplifiers., EEG Clin. Neurophsiol. 11:814-816).

Frequency

Every scientist and engineer faces the frequency measurement problem. This is a very complicated topic, because usually we don't know what kind of frequencies we are looking for and we don't know what frequencies have bigger "value". Usually the most difficult tasks are to measure extremely low or extremely high frequencies. Possibly the most valued tool for frequency measurements is the calculation of the Fourier series. In electronics possibly the easiest way of measuring frequency is the calculation of random period Fourier series (Kivinukk and Pallas, 2002), see **Equation 5**.

Random period Fourier series, **Equation 5**.

$F(Tx / 2\pi) \approx a_0 / 2 + \sum (a_k\cos(kx) + b_k\sin(kx))$

Where:

T – period

$a_k = 1/\pi \int f(Tx / 2\pi) \cos kxdx, \quad k = 0, 1, 2,....$
$b_k = 1/\pi \int f(Tx / 2\pi) \sin kxdx, \quad k = 1, 2,....$

Sometimes it is useful to use the Fourier series as complex equation, the Euler's equation. See **Equation 6**.

$\cos(\varphi) = (e^{i\varphi} + e^{-i\varphi}) / 2 , \quad \sin(\varphi) = (e^{i\varphi} - e^{-i\varphi}) / 2i$ **Equation 6**

More practical information how to use Fourier series in electronics, from the signal processing aspect can be read from a whitepaper by (Agilent Technologies, 2000).

For those, who are interested in a wider picture, sources like (Kovacevic et al., 2013, Tao and Li-ming, 2013) should be recommended. However, the Fourier series is not the only frequency calculation method. There are many other possibilities, like the usage of the wavelets or something more interesting (Byrne, 2013).

4.1.7. VECTORS AND IMPEDANCE VECTOR DIAGRAM

Electronics seems easy, as long, as the equations describe direct current (DC) related events. Difficulties arise when someone wants to describe frequency related problems and where alternating current (AC) is used. In that case the word resistance has to be replaced with “impedance” and alternating functions like **sin** and **cos** have to be taken into account.

In case of impedance related measurements, the result can be shown as complex diagram, see **Figure 3**.

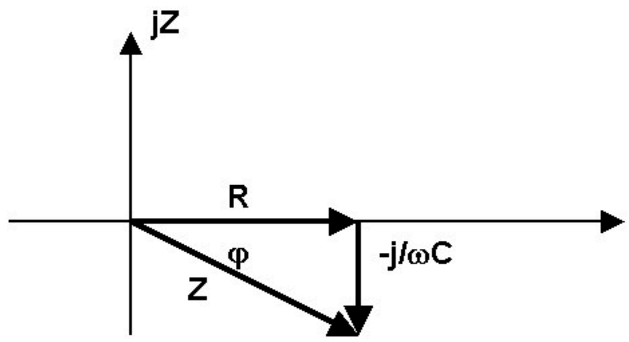

Figure 3. *The complex impedance diagram.*

Where:
R – resistance
-j/ωC – capacitance related frequency related component
Z – the complex impedance

More detailed information can be read from a book by (Horowitz and Hill, 2001).

Power

In DC circuits power is the product of U and I, as seen in **Equation 7**.

$P = U \bullet I$, **Equation 7**.

In more complicated situations (Horowitz and Hill, 2001), it would be wise to add up all the little pices, to integrate. In that case, **Equation 7** transforms into **Equation 8**.

$P = 1 / T \int U(t) \bullet I(t)\, dt$, **Equation 8**.

Where:

T – time period
U(t) – voltage over the timing of t
I(t) – current over the timing of t

4.1.8. ERRORS, ACCURACY AND PRECISION

Errors are always an integral part of any measurement device or system. This book mentions only 4 types of error: the random error, the systematic error, the quantization error and the dynamic error. Usually there 2 types of books: the one's that describes very little and the one what describes too much mathematics. From the biomedical engineering side of view, a book by (Webster, 2004) can be recommended.

Random error

Random errors are caused by some kind of statistical fluctuations and these can be removed with proper statistical methods. Usually averaging helps.

Systematic error

Systematic errors always have the same "size" and they appear in the same direction but can't be removed with averaging. So one has to build extra formula what helps to minimize the systematic error.

Quantization error

Quantization error is the difference between the signal's original value (the analog signal) and and the value aquired after digitazation. Since all analog to digital converters (ADC) perform quantization, ADCs should be treated as first sources of quantization errors.

More information about quantization noise of sinusoidal signals can be optained from an article by (Alcazar and Santos, 2009). The mathematics aspect of the quantization error is well described in an article by (Kabal, 2011).

Dynamic error

Also called as measurement error. Dynamic error is the difference between the true value changing compared to the value the system is showing. This is a problem among digital to analogue converters (DAC). More detailed information can be read from an article by (Kong and Galton, 2017).

Accuracy

Many different books and articles define accuracy and resolution very differently. According to (AN114, dataforth.com) the accuracy is the device's degree of absolute correctness and resolution is the minimal value measurand the system is able to detect. The same ideas but with very different words can be found from a book by (Webster,2004). Maybe one of the problems is related to the fact that "accuracy" means different things when different signals are measured with different sensors.

Precision

Precision indicates how much the measurands deviate from each other. Quite often precision is described as bullet-like points on circular target.

4.1.9. TIME RESPONSE

In a general sense the time response is something we measure with a signal generator and the oscilloscope. The signal generator generates signals what should model the actual situation of the working system and the oscilloscope measures the waveforms and sometimes calculates something. Digital oscilloscopes also store the measured data in the computer and take screenshots.

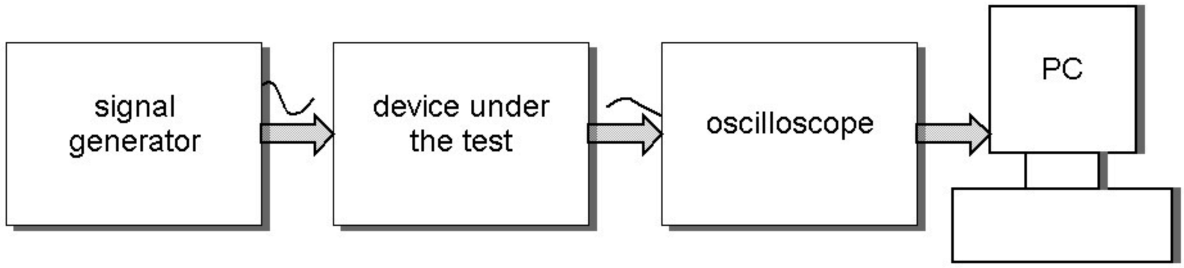

Figure 4. *The testing of the system's time response.*

Figure 4 describes the situation and here one can see that the signal generator generates a sinusoidal signal but the device under the test causes some kind of signal delay and so the oscilloscope and the PC show some kind of different signal.

Finding the right test signals for the signal generator can be an another great headache because the typical step functions can be too simple for the case and therefore not model the real situation. It is always good to search for test signal graphs – to find out what kind of waveforms are used, how many harmonics are summed with each other and what are the multiplication related parameters (Geddes and Baker, 1989). For example, there is always a problem how to model the ECG signal. One possible idea is to use Matlab environment to create the simulated ECG signal (Edelmann et al., 2018).

References

P.R. P-Alcazar and A. Santos, 2009

Behavior of quantization noise for sinusoidal signals. A revision.
Journal of Applied Research and Technology, Vol. 7, No. 2, pp. 136-152

An and Stylios, 2020

Comparison of Motion Artefact Reduction Methods and the Implementation of Adaptive
Motion Artefact Reduction in Wearable Electrocardiogram Monitoring,
Sensors 2020, 20, 1468; doi:10.3390/s20051468

Belo et al., 2017

Biosignals learning and synthesis using deep neural networks,
BioMed Eng OnLine (2017) 16:115
DOI 10.1186/s12938-017-0405-0

E.C. Bosch & E. Hartmann, 2003

ECG Front-End Design is Simplified with MicroConverter,
Analog Dialogue 37-11, November 2003

C.L. Byrne, 2013

Mathematics of Signal Processing: A First Course,
University of Massachusetts Lowell, Department of Mathematical Sciences

J.-C. Edelmann et al., 2018
An ECG simulator with a novel ECG profile for physiological signals,
Journal of Medical Engineering & Technology, Vol. 42, No. 7, pp. 501-509
https://doi.org/10.1080/03091902.2019.1576788

L.A. Geddes and L.E. Baker, 1989
Principles of Applied Biomedical Instrumentation, Third edition
ISBN: 0-471-60899-8

T. Glover and K. Mitchell, 2002
An introduction to biostatistics, McGraw-Hill
ISBN: 0-07-241841-9

P. Gupta et al., 2015
Baseline wander removal of electrocardiogram signals using multivariate empirical Mode decomposition,
Healthcare Technology Letters, 2015, Vol. 2, Iss. 6, pp. 164-166
doi: 10.1049/htl.2015.0029

V. Heinrichsen, 1996
Signaalide analoogtöötlus,
Tallinna Tehnikaülikool, Raadio- ja sidetehnika Instituut

Horowitz & Hill, 2001
The Art of Electronics,
Cambridge University Press, 2001, ISBN: 0 521 37095 7

Imtiaz et al., 2016
ECG artefact identification and removal in mHealth systems for continuous patient monitoring,
HealthcareTechnologyLetters, 2016,
Vol. 3, Iss. 3, pp. 171-176, doi:10.1049/htl.2016.0020

C.J. James and Christian. W. Hesse, 2005
Independent component analysis for biomedicalsignals,
Physiol. Meas.26(2005), R15-R39
doi: 10.1088/0967-3334/26/1R02

P. Kabal, 2011
Correlation Properties of Quantization Noise,
978-1-4577-0539-7/11/, IEEE

Kivinukk and Pallas, 2002
Harmooniline analüüs ja funktsioonide lähendamine,
ISBN: 9985-59-254-9

F.T. Koide, 1997
Common-Mode Rejection Ratio Redefined,
IEEE Transactions on Instrumentation and Measurement,
Vol. 46, No. 3, June 1997

D. Kong and I. Galton, 2017
Adaptive Cancellation of Static and Dynamic Mismatch Error in Continous-Time DACs,
IEEE Transactions on Circuits and Systems-I: Regular Papers,
Digital Object Identifier 10.1109/TCSI.2017.273798

J. Kovacevic et al., 2013
Fourier and Wavelet Signal Processing

J. Kärner, 1997
Sissejuhatus arengubioloogiasse,
Tartu Ülikooli Kirjastuse trükikoda, ISBN: 9985-56-284-4

G. Lenis et al., 2017
Comparison of Baseline Wander Removal Techniquesconsidering the
Preservation of ST Changes in the IschemicECG: A Simulation Study,
Computational and Mathematical Methods in MedicineVolume 2017,
Article ID 9295029, 13 pageshttps://doi.org/10.1155/2017/92995029

P.J. Metting, PhD, 1976
PreTest SelfAssessment and Review, twelfth edition,
McGrawHill Medical, 1976, ISBN: 978-0-07-147663-8

J. Rahul et al., 2019
An overview on Biomedical Signal Analysis,
International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume 7, Issue 5, January 2019

K.M. Rasheed, 2017
ECG Mishaps, Artifacts and Operator Faults,
Bangladesh Crit Care J, March 2017, 5(1), pp. 63-67

G.W. Rowe, 1997
Theoretical models in biology. The origin of life, the immune system and the brain,
Oxford Science Publications, 1997
ISBN: 0 19 859687 1

A.R. Perez-Riera et al., 2017
Main artefacts in electrocardiography, review article
Ann Noninvasive Electrocardiol. 2018;23:e12494

R.F. Schmidt and G.Thews, 1997
Inimese Füsioloogia, Tartu Ülikooli Füsioloogia Instituut,
ISBN: 9985-60-309-5

Ü. Sentürk et al., 2019
Towards wearable blood pressure measurement systems from biosignals: a review,
Turkish Journal of Electrical Engineering & Computer Sciences,
27:3259-3281, doi: 10.3906/elk-1812-121

Tao and Li-ming, 2013
Mathematical theory of signal analysis vs. complex analysis method of harmonic analysis,
Appl. Math. J. Chinese Univ., 2013, 28(4): 505-530

T. Togawa et al, 2011
Biomedical Sensors And Instruments, second edition
CRC Press
ISBN: 978-1-4200-9078-9

J.G. Webster, 2004
Bioinstrumentation,
John Wiley & Sons, Inc.
ISBN: 0-471-26327-3

MT-042: Op Amp Common-Mode Rejection Ratio (CMRR)
Analog Devices, Rev.0, 10/08, WK

Agilent Technologies, 2000
The Fundamentals of Signal Analysis, application note 243

AN114, dataforth.com

4.2 THE BIOSIGNALS MEASURED BY THE ELECTRONIC BABY MONITORS

4.2.1. THE SIGNALS

There is always a question, what kind of signals to measure. Usually doctors agree that blood preassure is the most important signal but it is quite difficult signal to measure. There are many signals to measure, but here we consider the following ones:

- ECG
- respiration rate/breathing rate
- temperature
- audio
- pulse oxymetry
- video

The reason why these signals are considered, is because these are easy to measure from a baby. Also, articles about baby monitors report about measuring these signals. So in principle, these 6 signals should describe the minimum amount of signals what is needed. The ECG, respiration rate, temperature and pulse oxymetry signals are really valuable signals. Audio is not the most important signal but it can detect snoring sounds or someone entering the house, trying to steal the baby. Video gives information about the baby still being in the bed, so it can be used as a monitoring device.

4.2.2. ECG

The generation of the ECG signal

Usually physiology studybooks describe the heart and the ECG signal generation. The heart has a complex structure, both from the mechanical and also from the electrical aspect. The heart consists of 4 chambers – atria-the 2 upper chambers and the ventricles – the 2 lower chambers. The heart muscle works because of the electrical signal what travels along it – starting from sinoatrial node, travelling along the AV-node, bundle of His and it's branches and ends where the Purkinje fibers are (Schmidt and Thews, 1997). The ECG signal is a sum of the electrical signals generated by the many cells along the way. The shape of the ECG signal depends on where and how it is measured. However, when the ECG signal is measured with electrodes between the hands and right leg (the Einthoven triangle), when always the same shape of signal is aquired as seen on handdrawn figure, the Figure 5.

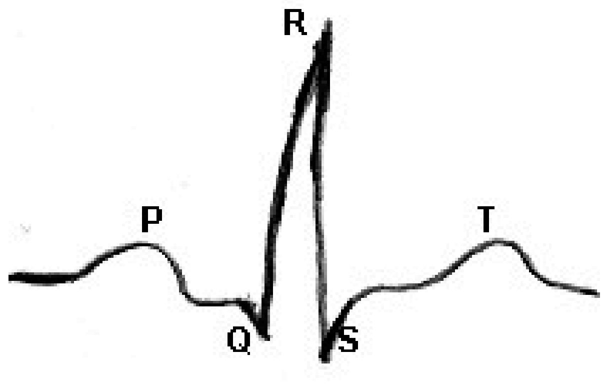

Figure 5. *The ECG signal according to the Einthoven triangle.*

The ECG signal as shown on Figure 5, shows the QRS-complex and the P and T-waves.

Usually biomedical engineering books describe the ECG signal very briefly, just like the signal described on **Figure 5.** However, this is not giving the whole picture about the problem. Therefore this book includes one picture, **Figure 6**, taken from a real ECG recording.

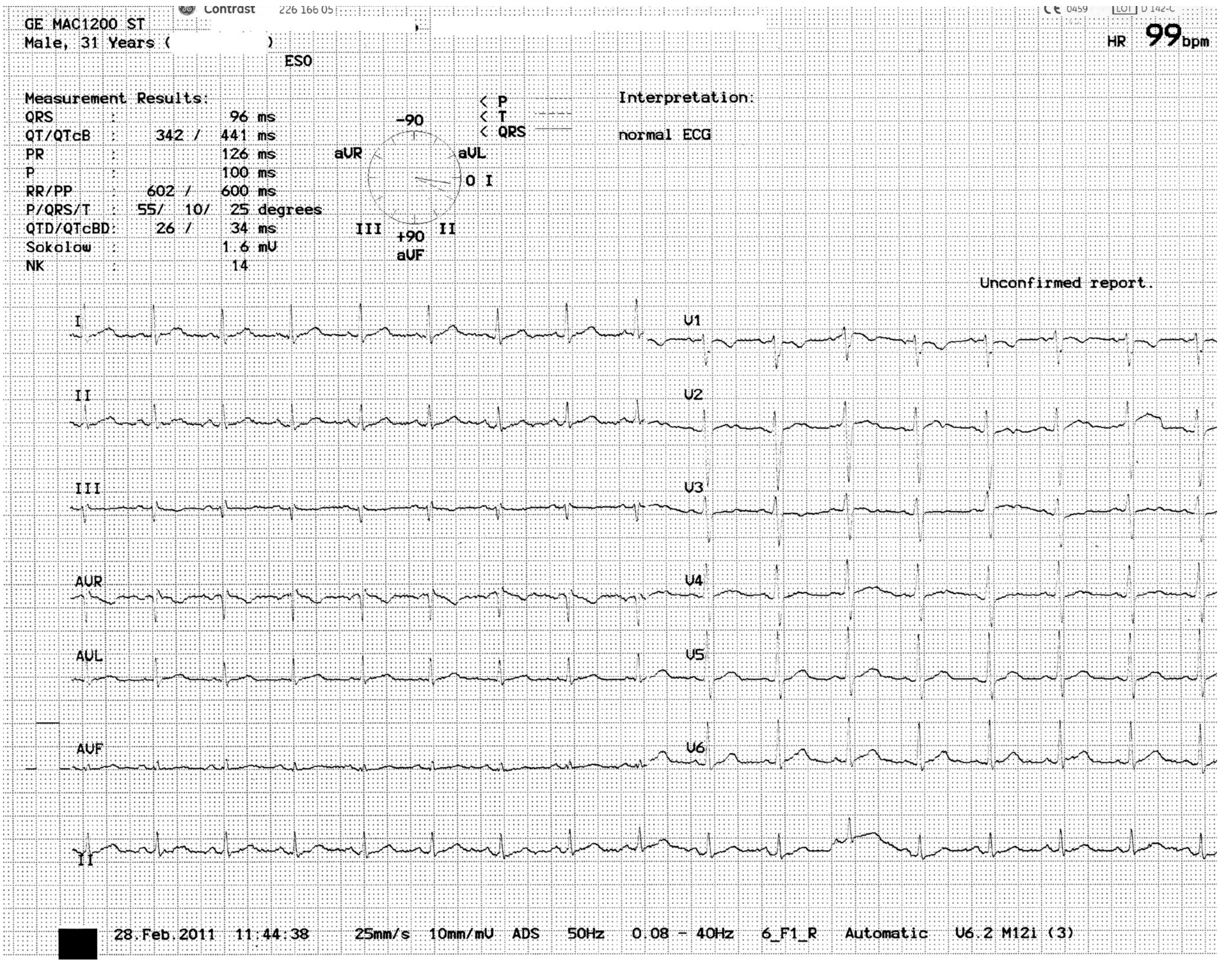

Figure 6. *The normal ECG as recorded from a 31 year old male.*

Figure 6 shows, the ECG signals measured according to different electrodes placed on the chest, the paper movement speed (25 mm/s), the resolution (10 mm/mV), the heart rate and some timings.

While recording the ECG signal, we have to think, what is the purpose of the measurement. When someone wants to record only heart rate, when a 1-electrode ECG measuring device or Foucault current measuring device is enough. When one wants to measure diagnostic values, many electrodes have to be used. The frequency range of the ECG signal depends on the purpose of the measurement: for diagnostic mode the frequency response range is 0.05 Hz – 100 Hz and for monitoring mode the frequency response range is 0.5 Hz – 40 Hz (Sigit et al., 2014). The most complex ECG signal is recorded with the 12-lead recording system (Webster, 2004). A book by (Malmivuo and Plonzey, 1995) is very recommended because of the information about the generation of the ECG signal.

The signal shapes of the ECG signal

The signal shapes of the ECG signal depend on the amount of electrodes used, placings on the body and the health related issues. The different signal shapes of the ECG signal describe the diagnostics of the heart related problems. The signal shapes are very complex and a good proffesional reads books what describes these ECG signal shapes. Some of these ECG signal books have long history. For example, Barney Marriott created “Practical Electrocardiography” in 1954 and it has been published in 10 editions (Wagner, 2001). There is another good ECG signal shape based book (Hampton, 2013). The whole topic of the ECG signal’s shape is very wide but here only some very basic aspects are mentioned according to (Sigit et al., 2014) and more details about it can be read from (Schmidt and Thews, 1997):

- P wave occurs due to atrium depolarization
- QRS complex occurs due to ventricular depolarization process
- T wave occurs due to ventricular repolarization
- PR interval indicates time of onset of atrium contraction to the beginning of ventricular contraction
- RT intervals show muscle contraction

ECG measurement methods, the leads systems

The ECG signal’s quality depends on the lead system used. In principle there are 3 lead systems used: the Einthoven leads, the Goldberger leads and the Wilson leads. For those who are interested in other lead systems, a book by (Malmivuo and Plonsey, 1995) is recommended. Here these lead systems are mentioned only very briefly because space is left for articles what describe the ECG measurement methods.

Einthoven leads

In 1908 Einthoven published an article about the recording of the ECG signal (Malmivuo and Plonsey, 1995). The Einthoven’s leads, also called the Einthoven’s triangle are based on the idea that the electrodes are placed on both hands and 1 foot.

Wilson leads

Wilson dreamed about ECG unipolar potentials. So he came up with the idea of using a central potential, according to which all other potentials are measured. In order to achive his idea, he placed 5 kΩ resistors to the ends of the leads and the other end of the resistors was common to all. So, in a sense, he measured average potential (Malmivuo and Plonsey, 1995).

Goldberger leads

Goldberger used the Wilson’s idea about leads but for every lead he removed one of the three resistors. He named these augmented leads (Malmivuo and Plonsey, 1995).

There is always a question, what kind of hardware to use for the data aquistion. The ECG signal aquistion has gone through many developments. In principle, usually the ECG signal is recorded with differential amplifiers or even instrumentation amplifiers. There are good electronics data sheets what describe the usage of ECG amplfier chips and also give some kind of overview about the design of the amplifers (AD8232 data sheet).

In order to improve the ECG signal's quality, many methods have been used, including the averaging, a simple method what helps to improve the QRS's signal to noise ratio (Christiansen et al.,1996).

An article by (Rovetta et al., 2017) describes the usage of the automatic gain control to improve the ECG aquisition. This article is recommended because it includes electronics circuits and equations.

An article by (Edelmann et al., 2018) describes a Matlab based ECG simulator and uses an ordinary sound card for signal detection.

An article by (Parak and Havlik, 2011) describes digital ECG signal processing and 3 heart rate frequency detection methods.

An article by (An and Stylios, 2020) describes the motion artefact reduction methods from the ECG signal and describes different signal filtering methods, like FIR, IIR and adaptive filtering. The article includes necessary equations and filter's frequency response plots.

The ECG recording has also reached into the world of Smartphones (Sigit et al., 2014).

The ECG data aquisition always need the useage of the proper electrodes and signal amplifiers. On Figure 7 some typical ECG electrodes are shown but considering the situation, there can be many different-looking ECG electrodes. Figure 8 shows an amplifier chip, named AD620ANZ. The AD620ANZ chip is a instrumentation amplifier chip manufactured by the Analog Devices and according to the data sheet's information, it can be used in ECG and medical instrumentation.

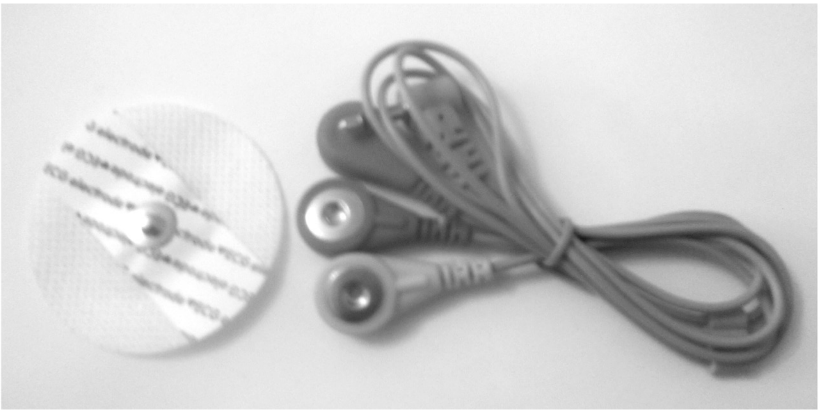

Figure 7. *The ECG electrodes.*

Figure 8. *AD620ANZ, the ECG amplifier chip.*

4.2.3. RESPIRATION RATE

The generation of the signal

In principle, we all are used to breath every day. Actually breathing is a phenomenon which includes different parts of our body, starting from the brain and ending with lungs and chest around them. Also breathing includes muscles and different neuron's groups. Considering this book's small volume, we are not going into details. However, the interested reader should read physiology books, like (Schmidt and Thews, 1997) or special sleep medicine book by (Kryger, Roth and Dement, 2017) what includes special sleep and breathing related chapters.

The sensors used

There are many different types of breathing and also because of that there are different breathing sensors in usage. For example, during polysomnogrpahic sleep medicine recording, the breathing is measured with thermistors placed under the nose and with indctive belt sensors placed onto thorax and abdomen area. With the help of this 3 sensors, it is possible to get very accurate information about the patient's breathing. Here, within this book we consider the respiration rate or special changes in it to be informative and other breathing related parameters to be secondary. The choice of criteria is based on the assumption that respiratory rate (RR) is a good signal for giving early warnings and it is relatively easy to detect. There are breathing related overiew articles what all-together describe almost every breathing measurement related device (Liu et al., 2019, Massaroni et al., 2019, Ginsburg et al., 2018).

The overview articles

By reading an article written by (Ginsburg et al., 2018) the reader gets an overiew of tools used to measure respiratory rate in order to identify childhood pneumonia. Here children are meant to be 5 years old or less. The article is based on 16 studies. The earliest study dates back into 1992. In essence, the article includes a table, having length 4 pages, what describes the author, the device, category, location, users, reference and the results.

An article by (Liu et al., 2019) describes recent respiratory rate (RR) measurement devices. The article categorized the devices into 3 modalities: extracting RR from other physiological signals, RR measurement based on respiratory movements and RR measurement based on airflow. The 235 articles used in the review belong into time window between 2000 and 2018.

An article by (Massaroni et al., 2019) describes contact-based respiration rate measurement methods. It includes a classification where the measurement methods are classified into the following classes: respiratory airflow, respiratory sounds, air temperature, air humidity, air components, chest wall movements and modulation of cardiac activity. This is a long article, consisting of 47 pages describing many different sensors.

4.2.4. TEMPERATURE

The generation of the signal

Intensity of molecular motions in a piece of body is expressed by the value of its temperature. This generates a complicated temperature distribution field around the body, what looks very different in hot and cold environments (Schmidt and Thews, 1997). Inside the body the hypothalamus area of the brain controls the temperature and it keeps the temperature "still" within +/- 1°C (Lim et al., 2008).

For humans, the usual body temperature is 37°C and a deviation of +/- 3.5°C can cause very serious problems (Lim et al., 2008). Heat transfer between the body and the outer environment occurs through conduction, convection, radiation and evaporation. According to (Ngarambe et al., 2019): "Sleep typically occurs when the core body temperature decreases, and body heat loss is at its peak". The body temperature is naturally rythmic – during the day it is warmer and at night it is colder. The interested reader can find more information from books by (Schmidt and Thews, 1997, Kryger, Roth and Dement, 2017).

The detection of the signal

Temperature measurement sensors can be easily classified into contact and non-contact based sensors. There are many different contact-based temperature measurment sensors but in most cases, they are not useful while detecting the sleeping patient. Therefore contact-based temperature detection sensors have found usage as parts of the smart mattresses, measuring the temperature distribution or some bigger body movements (Kala, 2016). Also, conductive textiles have been used for the detection of the neonate's temperature (Saurabh et al., 2014). Although non-contact temperature measurement sensors can be very sensitive, the huge movements of the sleeping patient make them useless.

There are articles describing the measurement of the environment's temperature (Saad et al., 2017, Ngarambe et al., 2019) and this data can help to predict the wellness of the room and how well the patient adopts with it. In such kind of cases also humidity and light levels are recorded.We have to remember that the human being is always a part of the environment and therefore record also the environment's parameters.

Some projects

In order to describe the problem in a more detailed way, some projects are referred. These projects describe in a detailed manner how smart jackets for neonates are designed and what problems can be expected. Maybe these projects don't describe anything extremely complicated but alltogether they describe the lookout of a "usual" smart baby jacket. As it can be seen from the articles, the ECG, pulse oximetry and temperature are the most commonly used signals. Also these projects describe the properties of smart textiles.

Case 1

An article by (Lugoda et al., 2018) describes a thermograph, a system what consists of 16 temeprature-sensing yarns built into wearable fabrics. The work includes Murata 10 kOhm, 100 mW NTC thermistors.

Case 2

An article by (Rao et al., 2014) describes low power remote neonatal temperature monitoring device. This wearable sensor system uses a microcontroller unit, bluetooth, 12 bit ADC, temperature sensor with analog front end, status LEDs, power supply, filter, 2.4 GHz antenna, 256 kb flash memory and 8 kB RAM. The consumable sleep current is 0.4 μA. The system runs on 3.3 V coin cell power supply. The system uses "direct interfacing", meaning that there is no special circuit, instead the sensor is interfaced to the microcontroller. The accuracy of the temperature sensing device is 0.1°C.

Case 3

An article by (Chen et al., 2010) describes smart textile designed for vital sign monitoring of the infants in the NICU (Neonatal Intensive Care Unit). The device consists of textile sensors, a reflectance pulse oximeter and waearable temperature sensor. During the design process 2 different electrodes(silver and gold) were tested. The wiring was implemented with conductive yarn. 6 textile electrodes are located at different areas of the jacket, so when one sensor becomes loose, others will give the data. The article also mentions that the leakage current has to meet the CF class 1 standard, the device has to be compatible with the hygiene and infection risks (washing at 60°C and cleaning plastics with alcohol) and also the device has not to be causing any allergenic reactions. During the design process, MATLAB was used for signal filtering (2 Hz Butterworth HPF, 70 Hz Butterworth LPF and a notch filter). The article also compares different types of electrodes and concludes that the best results are obtained by the usage of large silver electrodes or small gold printed electrodes.

Case 4

The aim of the study (Yi and Song, 2020) is to design textile baby vest what would monitor the baby's body temperature with the usage of the conductive yarns. 5 samples of textile electrodes were developed. The textile electrodes have a 1-5 MΩ/cm2 impedance. During the design process 2 vest prototypes were designed. NTC thermistor was used as a temperature sensing device. The article also displays tables with material properties of the baby vest.

4.2.5. AUDIO

The generation of the audio signal: the speech and the cry

The amplification of the audio signal is probably the oldest sub-field of electronics. Almost every electronics engineer has designed some kind of audio amplifier. This field of electronics has a lot of literature about the human hearing, sound generation, amplification, processing and transmission. In principle, the designer has 2 choices: to design a system by himself or buy a audio-amplifier chip and add resistors and capacitors to it. Both choices have their own pros and cons. While talking about baby monitors, the signal lies in the audio range and usually does not need much signal processing. However, there might be cases when the signal is very low or there is a lot of background noise. Therefore proper knowledge about the signal amplification, filtering and processing is useful. The interested reader should read a book by (Eiskop and Sillart, 1988).

The microphones

The choice of the microphone sets the sound's spectral "outlook", and therefore the "tone" of the voice. The electrodynamic, static, magnetic, piezo and condenser microphone all give different results. It is not a problem when you want to detect only the cough sound, give a warning based it and say it is all. But it is a problem, when you want to make spectral analysis. The choice of microphones is wide but the microphones in common usage, everyday electronics projects look like something like the one on **Figure 9.**

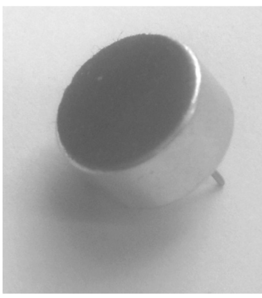

Figure 9. *A typical audio microphone.*

Signal amplification

In it's easiest sense, the audio signal amplification can be done with a 1-transistor class A amplifier with the addition of some resistors and capacitors as seen in **Figure 10.** Here a common-emitter amplifier is shown. It has large voltage gain.

C1 – coupling capacitor
C2 – bypass capacitor

R1 and R3 – the "voltage divider" resistors, define the amplification

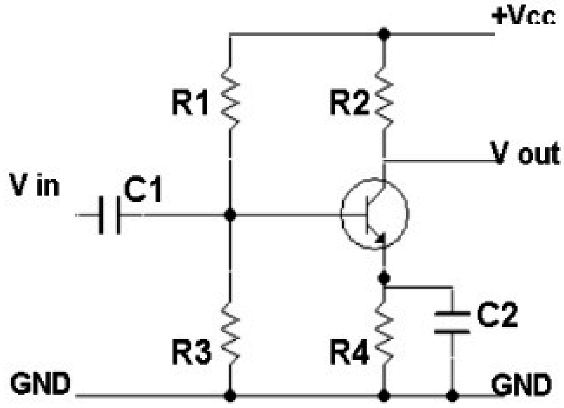

Figure 10. *The 1 transistor amplifier circuit.*

When there are problems with the matching of the microphone and the amplifier, the usage of chips can simplify the problem because the amplifiers built on a chip usually have good properties like low input noise voltage, high gain, wide bandwidth, low distortion and good CMRR. There are many audio amplification related chips, for example (LM833-N, OPA-167X). The audio amplification related chips can be seen in **Figure 11.** Also, considering the possiblities of destroying the amplifier with high currents or voltages, it is wise to add something for limiting the incoming signal and install the amplifier into a socket, so it can easily be replaced.

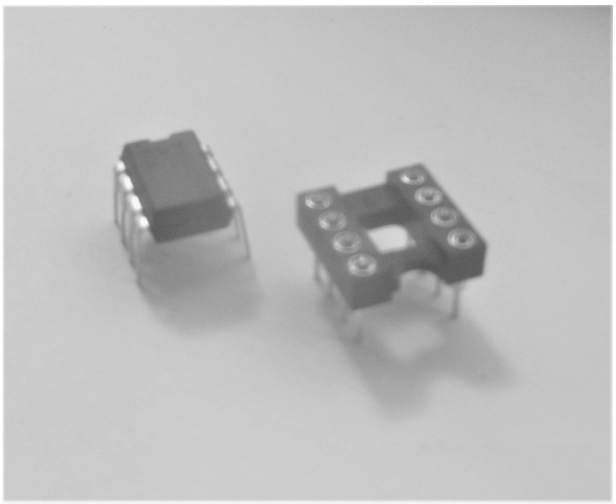

Figure 11. *A photo of an audio amplifier LM 833 chip and a socket.*

Filtering

Audio signal filtering offers the possibilities to use analog and digital filtering and mixing them. Analog filtering offers the possibilities to use high-pass, low-pass, bandpass, bandstop and notch filters. The digital filtering can be very complex and therefore offer many advantages over analog filtering but it can also be limited by the usage of the signal sampling frequency, the complexity of the algorithms and the speed of the clock circuit (Webster, 2004).

Signal processing

Often electronics engineers use microcontrollers for everyday simple signal processing. This can be a good and easy choice when only low-quality (low sampling rate) audio signals are under consideration. For more advanced special cases DSP chips should be recommended. Here are 2 different examples:

Very complicated audio digital signal processing (DSP) can be done with the usage of special chips. For example there is a special 28/56-bit audio processor chip with 2 ADCs and 4 DACs (ADAU1701 datasheet). The chip works with voltages between 1.8 V and 3.3 V. The usage of the chip can be described for example in an article by (Merchel and Kormann, 2014).

There is a special audio system-on-chip DSP chip with analog interface (TAS3202 data sheet). The chip includes: 102 dB ADC, 105 dB DAC, 2 differential stereo analog inputs, 1 differential stereo output DAC, 2 serial audio inputs, 2 serial audio outputs, 135-MHz maximum speed, 44 kHz sample rate in clock master mode, single 3.3 V power supply.

4.2.6. PULSE OXIMETRY

Pulse oximetry is a method, first discovered in 1935 (Gay, 2018). In essence, the pulse oximtery is a method, where a tissue is monitored by passing red or infra-red light into it and measuring the the amount of light what passes the tisuse (transmissive method) or reflects from the tisuse (reflectance method). For best results two different lights, red (660 nm) and infra-red (940 nm) light are used in either in transmissive or in reflectance method.

The reason why red and IR lights are used lies in the absorbotion spectra.

The pulse oximeter measures the percentage of hemoglobin, having acceptable values between 94% and 99%. Hemoglobin is a protein in blood what carries oxygen and since the diagnostic value of the pulse oximeter. The pulse oximeter finds a lot of usage in the sleep medicine because when the percentage numbers start falling, it usually coincindences with some kind of obstruction or other breathing limiting event. The situation is illustrated on **Figure 12** (Aroul, 2014).

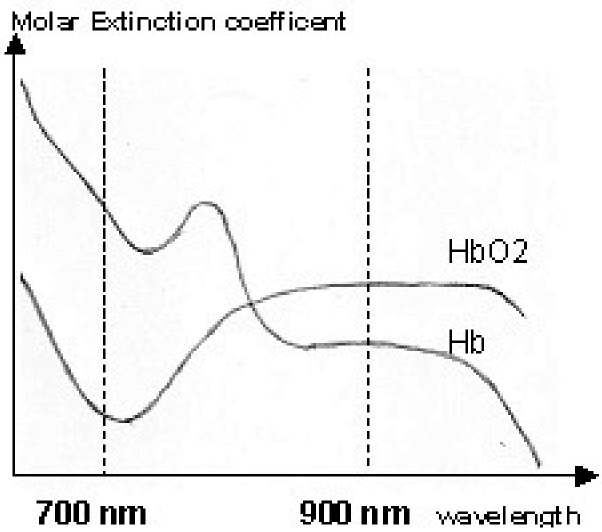

Figure 12. *The spectra of HbO2 and Hb according to (Aroul, 2014).*

Usually pulse oximeters are placed onto fingertip or connected to the earlobe. Because of this easy implementation, the pulse oximeters have found usage everywhere in medicine. Quite often articles describe the SpO2 numbers but while searching for bigger picture, it is important to understand the apnea-hypopnea index (AHI) because this describes the number of apneas and hypopneas during sleeping and it has diagnostic value(is it bigger than 15 events per hour?) but the SpO2 numbers (per centage) may change sometimes very fast but because of that the patient does not have to be sick (Gay, 2018).

It is common knowledge that sleep medicine related organizations want to publish pulse oximetry related whitepapers and internet is full of articles what describe the usage of the pulse oximeters. Because of that, only some articles are mentioned.

An article by (Ng and Chan, 2013) describes a review of normal values of infant sleep polysomnograpgy and this means also the interpretation of the oximeter's values.

An article by (Pretto et al., 2013) is an article what describes pulse oximetry's clinical usage guidelines in different settings. For example, what to expect during spot check, during the detection of nocturnal breathing disorders, during critical monitoring and in the operating theatre.

An article by (Casal et al., 2019) describes sleep-wake stage classification using heart rate signals from pulse oximetry. In the article AHI detection algorithm is described. In total 70 parameters were extracted but the article only mentions some of them, like different entropies and complexities.

The devices used for measurement

Today the pulse oximeters have found usage in many different devices and within many different designs. Because of that, the design principles of only some devices are described. Usually pulse oximeters consist of the light emitting diodes (LEDs), the light detecting devices (photodiodes or phototransistors) and signal processing circuitry. Because the signal processing circuitry may vary a lot from device to device, only a IR-LED and a IR-phototransistor are showed on **Figure 13.**

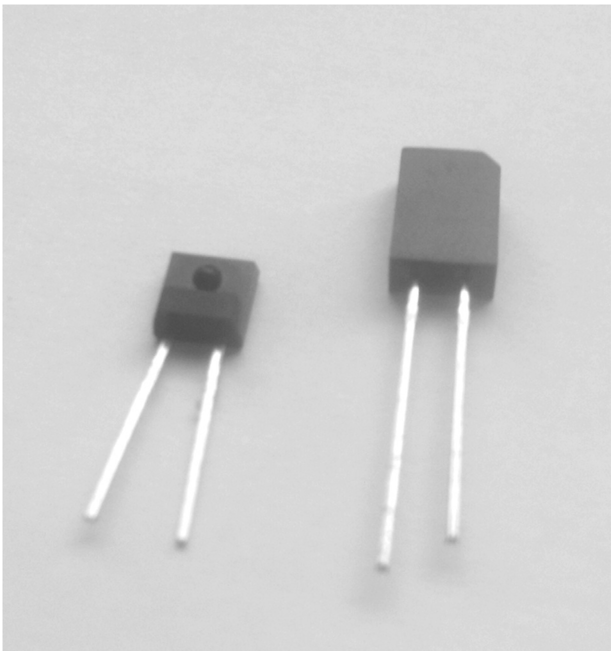

Figure 13. *The IR-phototransistor(left) and IR-photodiode(right).*

Case 1

Pulse oximeter design using Microchip's analog devices and dsPIC digital signal controllers (AN1525 datasheet, by Z. Feng). The datasheet includes a drawning where IR and Red LED are shown together with Photodiode and a Transimpedance Amplifier, microcontroller and some other additional components. The LED's current/intensity is controlled by a 12 bit Digital to Analog Converter (DAC), which is driven by the microcontroller. Also the datasheet includes a waveform displaying the pulse signal, a program flowchart and a sample calibration curve.

NB! This demo is meant solely for evaluation and development purposes. It is not intended for medical diagnostic use.

Case 2

This is a miniaturized pulse oximeter reference design's user's guide and test report (TIDA-00311, Aroul, 2014). According to the author (Aroul, 2014): "The scope of this document is to provide a miniaturized pulse oximeter reference design for high end clinical application".

The document describes special Analog Front End's (AFE4403) work. The circuitry includes 2 LEDs (Red and Infrared) and a photodiode based sensor.

Case 3

This case (Stojanovic and Karadaglic, 2013) uses very hardware based approach for solving the problem: the FPGA and the LEDs. Here the authors have discovered that a LED can also work as a detector for wavelengths smaller than the ones it emits. So, a system can be built using a FPGA what drives one LED, acting as a light emitting device and another LED acting as a light detector. Because of the flexibility of the FPGA, multichannel devices can be made. Also, this means that there is no need for special conditioning electronics and so helps to minimize the amount of components needed. The same can be achived with the usage of the microcontroller but the microcontroller is a software driven device and this can be a problem in case a multichannel data aquistion is going on. The FPGA is a hardware based device and thus it makes a much stronger.

Case 4

An article by (Mendonca et al., 2020) describes an oximeter device designed for the detection of OSA. The SpO2 signals were recorded with the Adult SpO2 sensor and having sampling frequency of 50 Hz and resolution 16 bits. Because the sampling frequency (50 Hz) of the sensor used in the hospital was lower than the signal on the sensor developed (100 Hz), the hospital recordings were resampled to 100 Hz. The device uses BITalino Core BT, that is microcontroller, communication module and powering (3.7 V Lithium). The device's average load current is 50mAh, meaning the device can last with a battery about 17 hours.

A total of 70 OSA patients were recorded, 19 females and 51 males and age range from 18 years to 82 years old. 22 features were created for each recording, having 2 features in time domain and 20 features in frequency domain. The device consisted of the pulse oximeter, microcontroller, bluetooth and microcomputer. The perfomance of the device was estimated by using the following metrics:

- average accuracy
- sensitivity

specificity
- area under the operating curve

The article also mentions the usage of the feedforward neural Network (FFNN) and the following FFNN parameters:

- kurtosis
- skewness
- mean
- relative power
- spectral entropy
- sample entropy
- Lempel-Ziv complexity
- central tendency measure

Thesis 1

This PhD thesis, “Mismatch of Sleep and Work Arrangements among Research and Development Employees and Personalisation of Sleep Studies”, written by Erve Sõõru in 2019 describes a pulse oxyimeter device, what has optic sensors and also electrical impedance sensors (Sõõru, 2019). This thesis takes the point that in the near future finger pulse oximeters have many different sensors and the data becomes more personalized.

Thesis 2

This thesis, “Nocturnal Pulse Oximetry Analysis in Sleep Medicine” is master degree thesis in biomedical technology, written by Sonia Catarina da Costa Cardoso in 2012 (Cardoso, 2012). The thesis tries to find mathematical models for pulse oximetry signal analysis.

References

P. Aroul, 2014
Miniaturized Pulse Oximeter Reference Design,
User’s Guide and Test Report, TIDA-00311, Texas Instruments

X. An and G.K. Stylios, 2020
Comparision of Motion Artefact Reduction Methods and the Implementation of Adaptive Motion Artefact Reduction in Wearable Electrocardiogram Monitoring, Sensors, 2020, 20, 1468, doi: 10.3390/s20051468

R. Casal et al., 2019
Sleep-wake stages classification using heart rate signals from pulse oximetry, Heliyon 5, 2019

S.C. da C. Cardoso, 2012
Nocturnal Pulse Oximetry Analysis in Sleep Medicine, to obtain Master degree in Biomeddical Technology, Escola Superior de Technologia e Gestao,
Instituto Politecnico de Braganca,
supervisor: E.M.M. Fonseca, co-supervisor: H. Ortleb

W. Chen et al., 2010
Design of an Integrated Sensor Platform for Vital Sign Monitoring of Newborn Infants at Neonatal Intensive Care Units,
Journal of Healthcare Engineering, Vol. 1, No. 4, 2010, pp. 535-554

Chu et al., 2019
Respiration rate and volume measurements using wearable strain sensors,
Npj Digital Medicine(2019), 2:8, https://doi.org/10.1038/s41746-019-0083-3

E.H. Chrisiansen et al., 1996
Noise in the signal-averaged electrocardiogram and accuracy for identification of patients with sustained monomorphic ventricular tachycardia after myocardial infarction,
European Heart Journal, 1996, 17, 911-916

Clenisha et al., 2018
Survey on automated child monitoring system using image processing,
International Journal of Pure and Applied Mathematics,
Volume 118 No. 24 2018, ISSN: 1314-3395 (on-line version)

J.-C. Edelmann et al., 2018
An ECG simulator with a novel ECG profile for physiological signals,
Journal of Medical Engineering & Technology, Vol. 42, No. 7, pp. 501-509
https://doi.org/10.1080/03091902.2019.1576788

I. Eiskop and A. Sillart, 1988
Akustika ja helitehnika, Tallinn “Valgus”, 1988
ISBN: 5-440-00378-9

Z. Feng, 2015
Pulse Oximeter Design Using Microchip’s Analog Devices and dsPIC Digital Signal Controllers, Microchip Technology Inc, AN1525

P.C. Gay, 2018
Overnight Pulse Oximetry Unwoven,
Journal of Clinical Sleep Medicine, Vol. 14, No. 4

L.A. Geddes and L.E.Baker, 1989
Principles of Applied Biomedical Instrumentation, Third edition
ISBN: 0-471-60899-8

A.S. Ginsburg et al., 2018
A Systematic Review of Tools to Measure Respiratory Rate in Order to Identify Childhood Pneumonia,
American Journal of Respiratory and Critical Care Medicine, Vol. 197, No. 9,
pp. 1116-1127, May 1, 2018

J.R. Hampton, 2013
EKG—see on lihtne, Kaheksas väljaanne,
Churchill, Livingstone, Elsevier,
ISBN: 978-9985-9049-3-0

Harding et al., 2019
The Temperature Dependence of Sleep,
Front.Neurosci. 13:336, doi: 10.3389/fnins.2019.00336

Horowitz & Hill, 2001
The Art of Electronics,
Cambridge University Press, 2001, ISBN: 0 521 37095 7

M. Kryger, T. Roth and W.C. Dement, 2017
Principles and Practice of Sleep Medicine, sixth edition, Elsevier
ISBN: 978-0-323-24288-2

Lim et al., 2008
Human Thermoregulation and Measurement of Body Temperature in Exercise and Clinical Settings, Ann Acad Med Singapore, 2008, 37, 347-53

H. Liu et al., 2019
Recent development of respiratory rate measurement technologies
Physiol. Meas. 40, 07TR01

P. Lugoda et al., 2018
A Wearable Textile Thermograph,
Sensors 2018, 18, 2369, doi: 10.3390/s18072369

J. Malmivuo and R. Plonsey, 1995
Bioelectromagnetism. Principles and Applications of Bioelectric and Biomagnetic Fields,
Oxford University Press, 1995, ISBN: 0-19-505823-2

C. Massaroni et al., 2018
Contactless Monitoring of Breathing Patterns and Respiratory Rate at the Pit of the Neck: A Single Camera Approach,
Hindawi, Journal of Sensors, volume 2018, Article ID 4567213

C. Massaroni et al., 2019
Contact-Based Methods for Measuring Respiratory Rate
Sensors, 2019, 19, 908, doi: 10.3390/s19040908

F. Mendonca, 2020
An Oximetry Based Wireless Device for Sleep Apnea Detection,
Sensors, 2020, 888, doi: 10.3390/s20030888

S. Merchel and L. Kormann, 2014
FreeDSP: A low-budget open-source audio-dsp module,
Proc. of the 17-th Int. Conference on Digital Audio Effects (DAFx-14),
Erlangen, Germany, September 1-5, 2014

D.K. Ng and C.-H. Chan, 2013
A Review of Normal Values of Infant Sleep Polysomnography,
Pediatrics and Neonatology, 2013, 54, pp. 82-87

J. Ngarambe et al., 2019
Effects of Changing Air Temperature at Different Sleep Stages on the Subjective Evaluation of Sleep Quality,
Sustainability, 2019, 11, 1417, doi: 10.3390/su11051417

Parak and Havlik, 2011
ECG signal processing and heart rate frequency detection methods
Conference: Technical Computing 2011, Prague

J.J. Pretto et al., 2013
Clinical use of pulse oximetry: Official guidelines from the Thoracic Society of Australia and New Zeland,
Respirology 2014, 19, pp. 38-46, doi: 10.1111/resp.12204

W.H.M. Saad et al., 2017
Study on the Effect of the Ambient Temperature toward the Quality of Sleep, International Journal of Electrical and Computer Engineering(IJECE), Vol. 7, No. 6, pp. 2986-2992, ISSN: 2088-8708, doi: 10.11591/ijece.v7i6.pp2986-2992

Saurabh et al., 2014
Continous Core Body Temperature Estimation via SURFACE Temperature Measurements using Wearable Sensors – Is it Feasible?
Proceedings of the International Conference on Biomedical Electronics and Devices(BIODEVICES-2014), pp. 181-186, ISBN: 978-989-758-013-0

R.F. Schmidt and G. Thews, 1997
Inimese Füsioloogia, Tartu Ülikooli Füsioloogia Instituut,
ISBN: 9985-60-309-5

G. Singh et al., 2020
Method of respiratory rate measurement using a unique wearable platform and an adaptive optical-based approach,
Intensive Care Medicine Experimental, 2020, 8:15,
https://doi.org/10.1186/s40635-020-00302-6

R. Stojanovic and D. Karadaglic, 2013
Design of an Oximeter Based on LED – LED Configuration and FPGA Technology, Sensors, 2013, 13, pp. 574-586, doi: 10.3390/s130100574

E. Sõõru, 2019
Mismatch of Sleep and Work Arrangements among Research and Development Employees and Personlisation of Sleep Studies, doctoral thesis,
Tallinn University of Technology, School of Engineering, School of Information Technologies, Department of Health Technologies,
Supervisor Professor Peeter Ross, Co-supervisor Professsor Aaro Hazak

H. Rao et al., 2014
Low Power Remote Neonatal Temperature Monitoring Device,
Proceedings of the International Conference on Biomedical Electronics and Devices
(BIODEVICES 2014), pp. 28-33, ISBN: 978-989-758-013-0

M. Rovetta et al., 2017
An automatic gain control circuit to improve ECG acquisition,
Research on Biomedical Engineering, Vol. 33, No. 4, pp. 370-374,
Doi: http://dx.doi.org/10.1590/2446-4740.04217

R. Sigit et al., 2014
Mini Wireless ECG for Monitoring Athletes’ ECG Signal Based on Smartphone,
IOSR Journal of Engineering (IOSRJEN)
Vol. 04, Issue 06, June 2014, pp. 13-18,
ISSN: 2250-3021

G.S. Wagner, 2001
Practical Electrocardiography, tenth edition
Lipincott, Williams and Wilkins, 2001
ISBN: 0-683-30746-0

J.G. Webster, 2004
Bioinstrumentation,
John Wiley & Sons, Inc.
ISBN: 0-471-26327-3

K.-H. Yi and H.Song, 2020
Development and Usability Test of Baby Vest Prototypes with a Body Temperature
Sensing Function, Journal of the Korean Society of Clothing and Textiles,
Vol. 44, No. 3, 2020, pp. 427-440, ISSN: 2234-0793,
https://doi.org/10.5850/JKSCT.2020.44.3.427

AD620 datasheet, www.analog.com

AD8232 datasheet, www.analog.com

ADAU1701 datasheet

TAS3202 data sheet

4.3 DATA COMPRESSION, STORAGE AND REPRODUCIBILITY

4.3.1 DATA COMPRESSION

There is always a question, what to do with the results. A high quality signal needs high sampling rate and therefore it means large amounts of data. So one has to ask, what are the minimal sampling frequencies and is there any possibility to compress the data. Also, data compression has to be such kind of one that it does not distort the signal during the reproducibility process.

Today data compression has been implemented in 2 ways: in hardware and in software. There are very many software based data compression methods. Data compression in hardware is usualy done by using FPGA, Soft Core Processor on FPGA and Hardcore processor (Savani et al., 2012).

According to (Yang et al., 2012) there are 2 types of data compression methods:

- Direct data compression techniques which treat the sample signals directly in the time domain
- Transformation based approaches in which the samples are transformed into another domain(for example: Karhunen-Loeve Transform, Discrete Cosine Transform, FFT, wavelet).

Often data compression methods are divided into 2 classes: lossy vs lossless. Lossless data compression methods are used when the decompression result has to be exact replica of the original source data. The compression in lossless methods is achieved by removing/adding the redundancy to the source data (Asolkar et al., 2013). Examples of lossless compression are Huffman coding, Arithmetic coding, Run length coding, Variable length coding and Golomb-Rice coding (Asolkar et al., 2013). Here is an example about lossless ECG signal compression methods (Hakkak and Azarnoosh, 2019). Here are 2 examples of lossy signal compression (Anjum and Chakraborty, 2014, Neira, 2019). An article by (Anjum and Chakraborty, 2014) describes a method how to achieve 2:1 compression with the ECG signal by using Turning Point Algorithm. An article by (Neira, 2019) describes how to apply fast wavelet signal processing to the ECG signal. Finally, one can say that there are 4 principles to be taken into account when a biosignal is compressed (Hadjileontiadis, 2006):

- Adoption of correct evaluation criteria
- Bandwith limitation and sampling rate reduction
- Redundancy reduction
- Information reduction

Here are some examples how data compression methods have been used:

An article by (Antonopoulos and Voros, 2017) describes a data compression algorithm for biosignals and it’s implementation in a hardware accelerator.

An article by (Said et al., 2018) describes deep learning for vital signs compression in a multi-user mHealth system.

4.3.2 DATA STORAGE

Today we have reached to the point where all devices produce data and gathering it all together is a challenge by itself. When it is a organization we may expect data to flow on several levels, not being only on the device level but also on the LAN level and be stored inside the server.

Of course someone may want to ask the why question – why do we need the data storage and all related to it. There are several reasons why:

- The data may help to build models
- The data may help to detect new diseases

There are also special databases what offer physiological-medical data. Because the internet addresses may change within time, we leave the search for the interested reader. Considering the practical aspect, we mention 3 articles what describe the blockchain (Hussein et al., 2019), Big Data (Khan, 2019) and cloud computing (Navale and Bourne, 2018). Finally, last but not least, we have to use the data printout. We are used to thinking that internet connection is always present and when needed, we call the IT-specialist but things can always go worse and under such circumstances reading the print out may be the only way.

While talking about baby monitors, one-night data size can be small enough to be recorded on the memory stick or some kind of portable storage (USB-hard disk).

4.3.3 DATA REPRODUCTION

You have the data, you keep it in the server and have a back-up copy. Now, suddenly because of who knows why you feel the urge to have a look on it. The first idea may be to have a print out – if possible. It is always a good idea to print the data from different printers because when you see how other people might see it. Also you may feel the urge to have a look on a monitor. Personal computers usually have small monitors, specially laptop computers and so it may be necessary to add a widescreen monitor. Connecting the cables is easy but things can go bad when the computer and monitor have different understandings and when the monitor stretches the screen wider. This is a situation what can't be allowed, otherwise you have wrong understaning about the signals. Therefore the lab should always have many different monitors, even when all of them are not in use in the same time.

References

M.S. Anjum and M. Chakraborty, 2014
ECG Data Compression using Turning Point Algorithm,
International Journal of Innovative Research in Engineering & Multidisciplinary Physical Sciences(IJIRMPS), Vol. 2, Issue. 6, December 2014, ISSN: 2349-7300

C.P. Antonopoulos and N.S. Voros, 2017
A Data Compression Hardware Accelerator Enabling Long-Term Biosignal Monitoring on Ultra-Low Power IoT Platforms,
Electronics 2017, Vol. 6, Issue. 54, doi: 10.3390/electronics6030054

P.S. Asolkar et al., 2013
Review of Data Compression and Different Techniques of Data Data Compression,
International Journal of Engineering Research & Technology (IJERT),
Vol. 2, Issue 1, January 2013, ISSN: 2278-0181

L.J. Hadjileontiadis, 2006
Biosignals and Compression Standards, in M-Health. Topics in Biomedical Engineering, by R.S.H. Istepanian, S. Laxminarayan, C.S. Pattichi (eds.)
DOI https://doi.org/10.1007/0-387-26559-7_21, ISBN 978-0-387-26559-9

H. Hakkak and M. Azarnoosh, 2019
Analysis of lossless compression techniques time-frequency-based in ECG Signal compression,
Asian J. Biomed Pharmaceut Sci, Vol. 9, Issue 66, ISSN: 2249-622X

Horowitz & Hill, 2001
The Art of Electronics,
Cambridge University Press, 2001, ISBN: 0 521 37095 7

A.F. Hussein et al., 2019
An Adaptive Biomedical Data Managing Scheme Based on the Blockchain Technique,
Applied Sciences, 2019, 9, 2494, doi: 10.3390/app9122494

M. Khan, 2019
Big Data: A Challenging Opportunity for Biomedical Informatics,
Amity Journal of Computational Sciences (AJCS), Vol. 3, Issue 1, ISSN: 2456-6616

V. Navale and P.E. Bourne, 2018
Cloud computing applications for biomedical science: A perspective
PLOS Computational Biology, Vol. 14, Issue 6

L. R. Neira, 2019
Effective high compression of ECG signals at low level distortion,
Scientific Reports, 2019, 9:4564

A.B. Said et al., 2018
A Deep Learning Approach for Vital Signs Compression and Energy Efficient Delivery in mhealth Systems,
IEEE Access, Vol. 6, 2018, doi: 10.1109/ACCESS.2018.2844308

V.G. Savani et al., 2012
Implementation of Data Compression Algorithms on FPGA using Soft-core Processor,
International Journal of Advancements in Technology, Vol. 3, No. 4,
ISSN: 0976-4860

S. Yang et al., 2012
Clinical Quality Guaranteed Physiological Data Compression in Mobile Health Monitoring,
MobileHealth 12, June 11, 2012, Hilton Head Island, SC, USA

CHAPTER 5

THE ACADEMIC ASPECT: THE THESIS

5.1 THE THESIS

5.1 THE THESIS

5.1.1. INTRODUCTION

Everybody knows what are the academic measures and it is always a pleasure when You have the possibility to read someone's thesis. During the writing process I discovered many thesis and because of that is this chapter. Books and articles describe what professionals have done and of course there is nothing new there. And the really valuable articles cost money. So, You want to know if there are any news and because of that thesis, no matter of what quality always offer some new ideas. Even if these ideas are not completely finished. Because there are so many theses, the data is presented as a table.

Author	Supervisor	Title	Univ. Name	Degree	Year
A. Nawaz	Prof. Kunal Pal	Development of an intelligent baby cradle for home and hospital use	National Institute of Technology, Rourkela	Bachelor of techn. In biomedical eng.	
A. Zykov	Sara Comai, Fabio Salice	Wearable computer sustem for remote health state monitoring	Politecnico di Milano, Sculo di Ingegneria dell'Informazione		2013
A. A. B. A. Jalil	Fairuz Rizal	Child Monitoring System (Child)	Univ. Malaysia Pahang	Bachelor of Electrical Engineering	2008
Lee Jian Der	K. Nisa Bt Khamil	Baby Health Band	Univ. Teknikal Malaysia Melaka	Bachelor of Electronic Engineering	2016
Ooi Young Tat	Soong Hong Cheng	Infant Monitoring aid and Managing Application (iMAMA)	Univ. Tunku Abdul Rahman	Bachelor of Computer Science	2016
Nada Elsheikh Babikir Mohammed	Dr. Abdulrahmman Karrar	Design and Development of Microcontroller Based Temperature and Humidity Controller For Infant Incubator	Univ of Khartoum	Bachelor of Electrical and Electronic Engineering	2011
Okoth John Akumu	Dr. Vitalis K Oduol	Electronic Child Monitoring Device	Univ of Nairobi		2004
Eric Yi-Kuo Jen		Design and Development of Wireless Baby Monitors	Simon Fraser University	Master of Engineering	2002
Charaf Eddine Mechalikh Rami Bouafia	Bachir Said	IoT Based System for Greenhouses Remote Monitoring and Climate Control	Kasdi Merbah University	Academic Master	2017
Marjolein Terhaard	Dr L.G. Vuurpijl, dr I.G. Sprinkhuizen-Kuyper, B.D. Williams	An Intelligent Monitoring System	Radboud University Nijmegen	Master Thesis	2009
Viorel Rotar	Preetham B. Kumar	Health State Monitoring System Design	California State Univ.	Master of Science in Electrical and Electronic Engineering	2012
Cansu YILMAZ Damla Ezgi AKÇORA Demet Sude SAPLIK İlker BOZCAN		Baby Monitoring System	METU		
A. A. Rhiannon Coppin Scott D. Kulchycki Mike Sjoerdsma Robert Trost Tim Wilder	Andrew Rawicz	Proposal for the Development of an Infant Monitoring System	Simon Fraser Univ.	Project proposal	1999
Xiaoting Liu, Kyle Takeuchi	Prof. Tokunbo Ogunfunmi and Mr. Shivakaumar Mathapathi	CMAG: IoT Baby Monitor	Santa Clara Univ.	Bachelor of Science	2017
Daniel Thomas White	Dr. Lily Laiho	Design of a non-contact home monitoring system for audio detection of infant apnea	California Polytechnic State University	Master of Science in biomedical engineering	2015

***Table 1**. The thesis.*

CHAPTER 6

THE STATISTICS, DATA ANALYSIS & SIGNAL PROCESSING

6.1 THE STATISTICS

6.2 THE DATA ANALYSIS

6.3 THE SIGNAL PROCESSING

6.1 THE STATISTICS

6.1.1. INTRODUCTION

One has to understand, does the signal look like expected or does it include some kind of error in it. And when an error is detected, there is always a question about the possible measures what have to be taken into account. When there are only few errors, the data by itself is small in volume and we know what has caused the errors, we can go even so far that we “blacklist” the errors in our own mind. This is one of the the reasons why new people in organisations come up with new ideas. When there are huge amounts of data and we want to be certain that we always see the same (right) thing, we design some kind of mathematical model for it and statistics is possibly the first tool we search for. As the reader knows, statistics has been in usage for long time and because of it the topic is very wide. Within this chapter only some ideas are presented: **The Math Tools** and **The Distributions**. Both of them are described only briefly – the author hopes that knowing these things could be helpful. For example produce some ideas what to do. When these ideas are not good enough, the reader has to search for special statistics-based literature. Luckily enough, there are books what describe most typical medical statistics methods (Peacock and Peacock, 2012), philosophical aspects about biostatistics (Michelson and Schofield, 1996) and mathematical methods (Grossman and Turner, 1974).

6.1.2. THE MATH TOOLS

There was a question – what kind of math tools are needed? Both, the electronic device with it’s signals running around and the human being offer many possibilities for statistics. So, in order to stay within some reasonable limits, the most commonly used math tools are described. Always things can become more complicated and need other tools. The interested reader should always collect more books and articles, otherwise there is a possibility that you start thinking in a certain manner just like all other people and lose the ability to see any mistakes or any novelty at all.

- Average / Mean
- Median
- Mode
- Standard Deviation
- Range
- Entropy

The Average / Mean

This is possibly the easiest parameter one can use. The arithmetic average can be defined as a sum of all values divided by the total number of values. See **Equation 1**.

In electronics, the mean describes the direct current (DC) signal.

$$\mathbf{EX = \sum x_i / n}$$

$$i = 1 \ldots n$$

Equation 1

Median

The median describes random value X's such value, when $p = 0.5$. The data is arranged in ascending order of size.

For a set of n values, the median is calculated as:

$$\mathbf{Me}\ X = (n + 1) / 2, \qquad F(\mathbf{Me}\ X) = 0.5$$

Equation 2 **Equation 3**

- Where F is a distribution function of X.
- When the distribution function is symmetrical, **E**X = **Me** X
- Geometrically the median discribes a situation where the distribution functions area can be split into two equally big (in means of surface) sub-areas (Jõgi, 2000).

Mode

The mode is the most frequently occuring value in a data set.

In symmetrical distributions, the mean **EX**, the median **Me** X and the mode are coincident (Glover and Mitchell, 2002).

Standard Deviation

In electronics, the standard deviation describes the alternating current (AC) signal. It tells us how far the signal deviates from the mean.

$$\mathbf{SD} = \mathrm{sqrt}(\textstyle\sum_{i}(x_i - \bar{x}) / n - 1)$$

$$i = 1 \ldots n$$

Equation 4

Range

The range describes the difference between the largest and smallest value of data.

For example,

Sample Range = Max(X) – Min(X).

Equation 5

Entropy

There are different aspects and different equations related to it. Do not confuse the equation what describes the gas and the equation what describe the information content of the message! Sometimes equations can look similiar, consist of same letters but have different meaning. For more interested readers, please see (Vedru and Pruulmann, 2012).

6.1.3. THE DISTRIBUTIONS

You have the data and what else could be better than presenting it on a graph. One picture tells more than hundred words and it holds true when dealing with data. A well designed graph can tell you what kind of data you have – what to expect and what kind of equations to use for it.

Of course, a wise person asks, why this is important.

Imagine a situation, when you have a electronic device what records data from a human being. This data keeps holding regular shape (pattern) in time domain and you are able to identify most important aspects of the signal. However, the signal is inherintly noisy and you can't filter noise out with a typical filter because when you would lose some signal. What makes it even worse, your device has to identify the signals and devide them into classes and because of the signals difficult shape and a lot of noise you can't filter with a typical Butterworth filter. So, one of the solutions is to filter signal and noise according to the distributions what they have on frequency domain. The situation can be described in a more detailed way on a **Figure 1**.

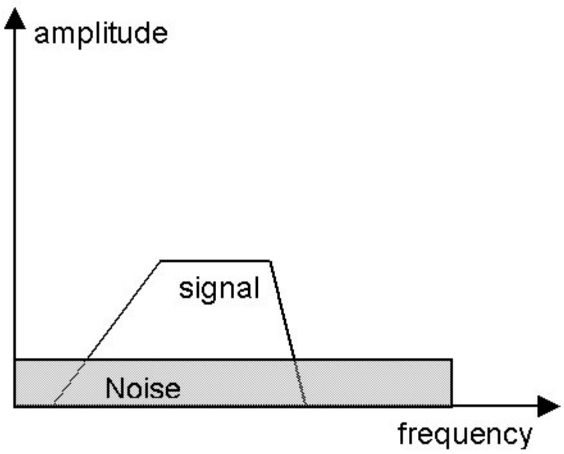

Figure 1. *The signal and noise overlappings.*

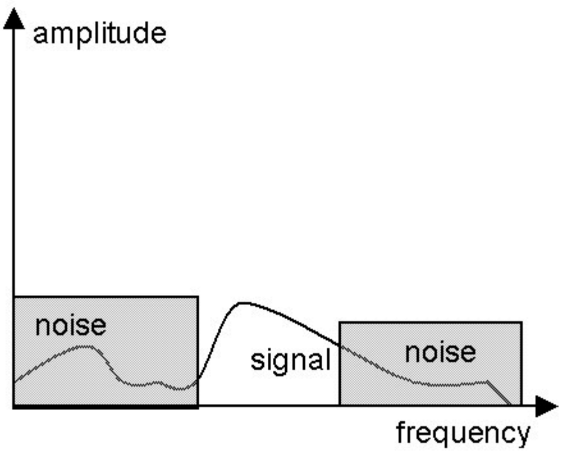

Figure 2. *Multimodal signal with noise.*

Figure 1 describes the signal and the noise having overlappings. Because of the simplicity the signal is shown as a trapedzoide but actually the signal can have any size and shape. This situation can be seen when you have a signal, where everything is true, no inference, no distortions...but everything is covered with white noise. Here simple filters can be used but things become more complicated when the signal and the noise have some strange patterns. For example when the signal has many frequency components and the noise appears only on some frequency bands. That kind of situation can be seen on **Figure** 2. As we can see from **Figure 2**, the noise appears on 2 different frequency bands and it is almost certain that filtering this causes at least some distortions to the signal.

Now we have seen some of the most common cases there typical filters still can help and what are described in many books and articles. However, things become more complicated when you have some kind of new signal (for example because of a new sensor) and the signal's outlook on time and frequency domain is unknown but complicated, as the results show. In such complicated cases distribution functions can help. Maybe this is not the best way to filter a signal but still better than nothing.

Here are some graphic tools: the Poisson distribution, normal distribution, binomial-distribution and the Data Regression. Of course, the interested reader has to keep in mind that there are more distributions and related issues to explore. Because of that some book and journal recommendations are given.

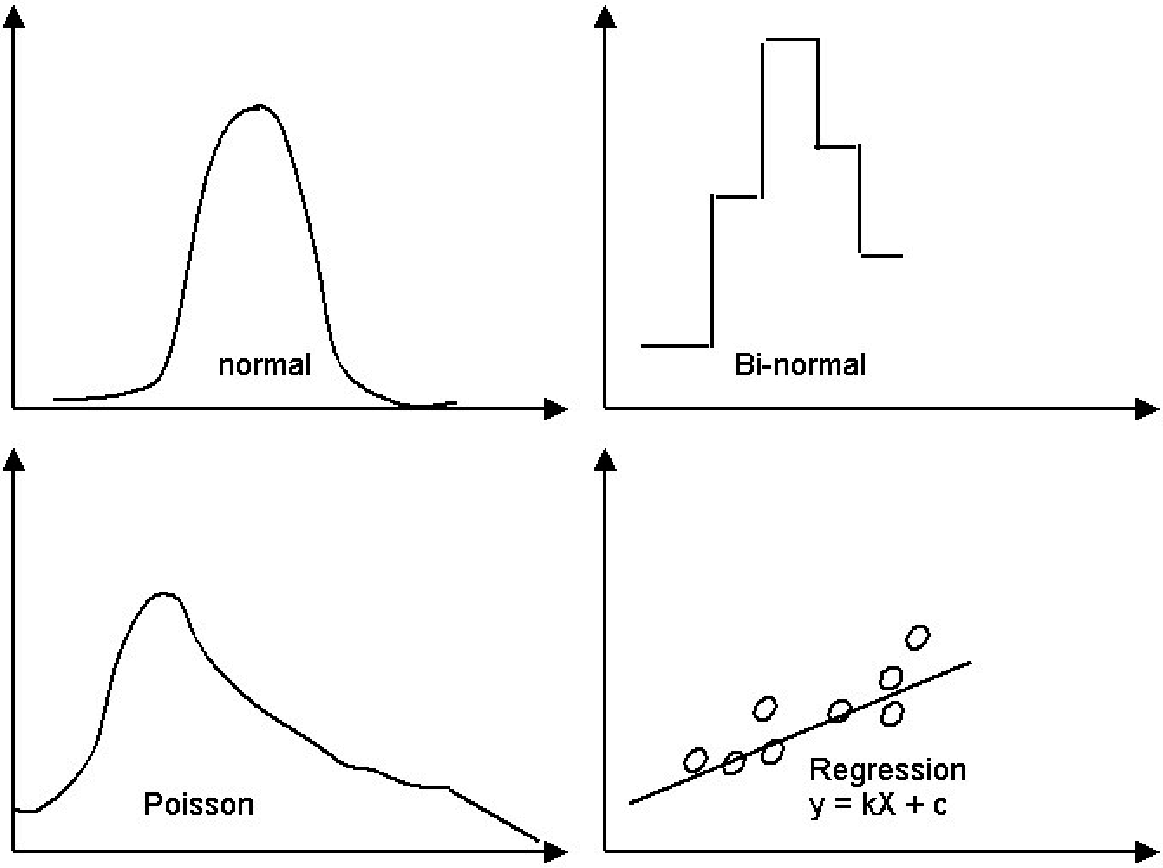

Figure 3. *The graphics tools: the distributions and the regression.*

Some literature to be recommended:

Some books:

Statistical and Adaptive Signal Processing
Spectral Estimation, Signal Modeling, Adaptive Filtering and Array Processing
Dimitris G. Manolakis, Vinay K. Ingle and Stephen M. Kogon,
Artech House, 2005, ISBN: 1-58053-610-7

The Scientist and Engineer's Guide to Digital Signal Processing
Second edition
Steven W. Smith
California Technical Publishing, 1999, ISBN: 0-9660176-6-8

Some articles:

A Review Paper: Noise Models in Digital Image Processing,
Ajay K. Boyat and Brijendra K. Joshi
Signal and Image Processing: An International Journal (SIPIJ), Vol. 6, No. 2, April 2015

An application of robust filters in ECG signal processing
T. Pander, XI Conference "Medical Informatics & Technologies", 2006

Time-Frequency Feature Representation Using Energy Concentration: An Overview of Recent Advances,
Ervin Sejdic, Igor Djurovic and Jin Jiang,
Digital Signal Processing, January 2009, 19(1): 153-183
Doi: 10.1016/j.dsp.2007.12.004

Digital filters in heart sound analysis,
L.H.Cherif, M.Mostafi and S.M. Debbal,
International Journal of Clinical Medicine Research,
2014, 1(3): 97-108

A Review of Classification Techniques of EMG Signals during Isotonic and Isometric Contradictions,
N. Nazmi, M. A. A. Rahman, S.-I. Yamamoto, S. A. Ahmad, H. Zamzuri and S.A. Mazlan
Sensors 2016, 16, 1304, doi: 10.3390/s16081304

6.2 THE DATA ANALYSIS

6.2.1. INTRODUCTION

You have the signals and you want to turn them into valuable information. What to do? This is a question what ghosts every scientist. Data analysis can help a scientist a lot but the big problem is the question – what is data analysis? Here we discuss only some methods, that is to say that the choice of methods mentioned here is not complete and the interested reader has to search for more.

This sub-chapter describes some data analysis methods what can be used in electronic systems and PCs, in order to make the system more intelligent and independent. Because of that 3 plus 1 data analysis methods, The Fuzzy, The Neuro and AI are described here. For the human being, a method called Meta – Analysis is recommended.

There are also many books (Maiväli, 2015, Kiley, 1999, Holmberg, 2007, Küttner and Jutman, 2007) and articles (Islam et al., 2018, Han, 2002, Zeger et al., 2004) what describe bio-data analysis.

6.2.2 THE FUZZY LOGIC

The Fuzzy System has been invented in 1965 by Lofti A. Zadech, proffesor for computer science at the University of California in Berkeley (Hellemann, 2001). The Fuzzy Logic has developed ever since a lot. Common to all Fuzzy Logic systems is the following structure:

the fuzzifer, inference engine, rule base, defuzzification (Baig, 2011). The relations between the components of the structure are described in **Figure 4**.

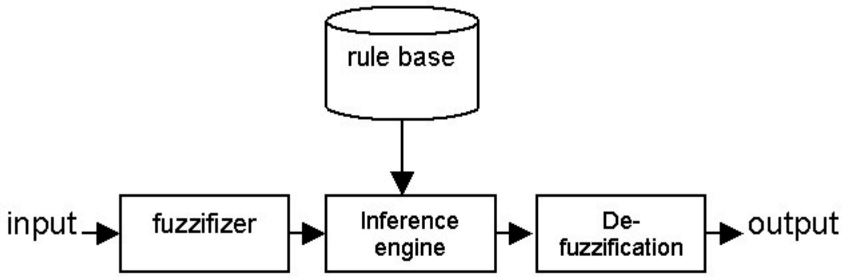

Figure 4. *The general Fuzzy system.*

The Fuzzy Logic uses IF-THEN type conditioning sentences in order to control the data. This type of logic is different from typical Boolean true vs not true algebra and helps to track vague information.

Let us expect that there is a system where a parameter changes so that Boolean logic can not be used for it. The parameter's behaviour is then divided into sub-sets and the behaviour's belongingness into the sub-sets is done with the design of the logic algorithm and the parameter's behaviour is described with some kind of function. Here only 3 logic functions, AND, OR and NOT are described but actually many more functions can be used. The AND, OR and NOT functions as graphical tools are described in **Figure 5**. The reason why all this strange logic is described, can be more easily seen when we have a closer look on 3 parameter graph, **Figure 6** – we see that the data can be represented without dicontinuties and the data can have difficult look-outs. This also means that very complicated controlling devices/systems can be designed.

Electronic components can have very difficult characteristics. It is not difficult to use them, it is the data interpretation what forces us to use only simple functions like AND, OR and NOT.

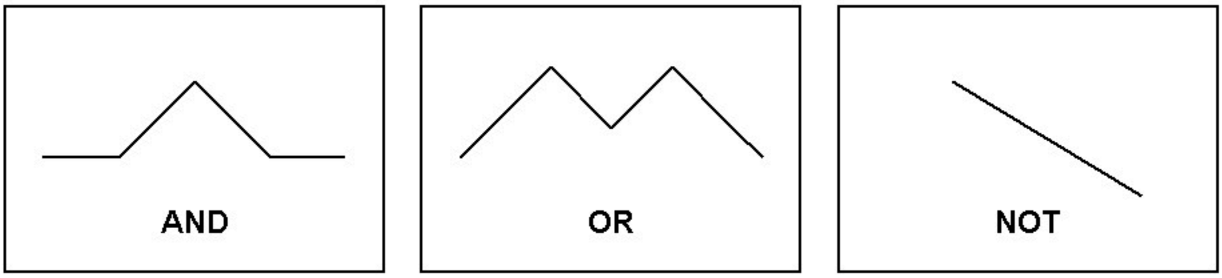

***Figure 5**. The Fuzzy logic elements: AND, OR and NOT, inspiration from https://www.mathworks.com/help/fuzzy/foundations-of-fuzzy-logic.html*

Typically “logic” systems are able to solve problems what can be described with simple functions. The Fuzzy Logic is able to solve multiple parameter functions and without discontinuties. The situation is very similar to the problem usually well described in Control Theory when trying to describe how to find a maximum/minimum in a 3 D space. For example, according to the picture described on **Figure 6**, the solution is in a place where the ball rolls (the minimum).

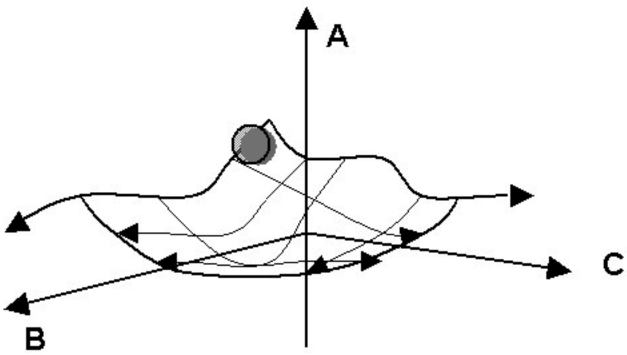

***Figure 6**. The 3 parameter continous problem.*

Books to be recommended:

Fuzzy and NeuroFuzzy Systems in Medicine, edited by Horia-Nicolai Teodorescu, Abraham Kandel, Lakhmi C. Jain, CRC Press, 1998, ISBN: 0849398061, 9780849398063

Articles to be recommended:

Design Model of Fuzzy Logic Medical Diagnosis Control System
Faran Baig, Saleem Khan, Yasir Noor, M. Imran
International Journal on Computer Science and Engineering (IJCSE), 2011, Vol. 3, No. 5, ISSN: 0975-3397

Type-2 Fuzzy Logic Systems,
Nilesh N. Karnik, Jerry M. Mendel and Qilian Liang
IEEE Transactions on Fuzzy Systems, 1999, Vol. 7, No. 6

A Comparison Between Fuzzy Type-1 and Type-2 Systems in Medical Decision Making: A Systematic Review,
A. Orooji et al., 2019
Crescent Journal of Medical and Biological Sciences, 2019, Vol. 6, No. 3, pp 246-252
EISSN: 2148-9696

6.2.3 THE ARTIFICIAL NEURONAL NETWORKS

The Artificial Neuronal Network, aka ANN. Sometimes these systems are called as "Neural Nets", "parallel distributed processing systems" or "connectionist systems" (Dongare et al., 2012). These systems were built by analysing human neuronal behaviour. Because of that, the fundamental unit representing the system is the neuron, a device what simulates human neuron's behaviour. This aspect can be described in more detail after becoming familiar with the general structure of the "typical" biological neuron. For example as seen on **Figure 7**.

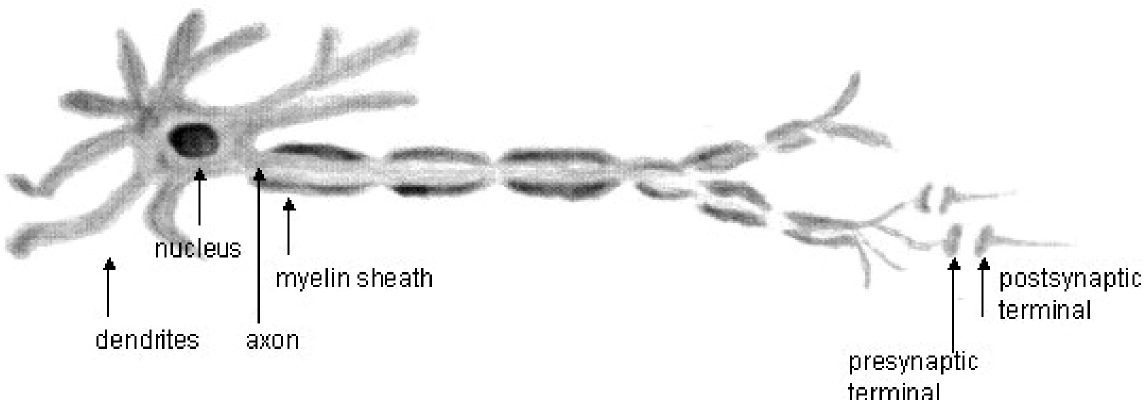

***Figure 7**. The biological neuron.*

As we can see, a "typical" biological neuron consist of dendrides, nucleus, axon and pre- and postsynaptic terminal. The axon is covered with myelin sheath. The dendrides gather the input information, the nucleus "processes the information" and the output goes on along the axon. The information from one neuron to another neuron is transmitted with signalling molecules what drift from presynaptic terminal (one neuron) to the postsynaptic terminal (the other neuron).

The same principles can be used in order to describe an electronic device, called artificial neuron. For example, we can draw such similarities:

biological neuron	**artificial neuron**
• dendrides	inputs
• nucleus	amplifier or some other active circuit
• axon	output

Such kind of similarities lead into desigining artificial neurons. Of course, there are major differences what can't be neglegted: the biological neurons process information in a parallel way, the artificial neurons process information in a serial manner. This is caused by the fact that the biological neurons gather information from thousands of other neurons and send to thousands other neurons, what is much more than the artifical neurons can do. Today there are many different artificial neuron types but possibly the easiest and maybe the earliest electronic neuron model is the McCulloch-Pitts model, designed in 1943 (Veelenturf, 1995). The artificial neural networks were first described in a Frank Rosenblatt's 1962 book called "Principles of Neurodynamics" (Veelenturf, 1995). The typical artifical neuron, as described previously, can be seen in a **Figure 8**.

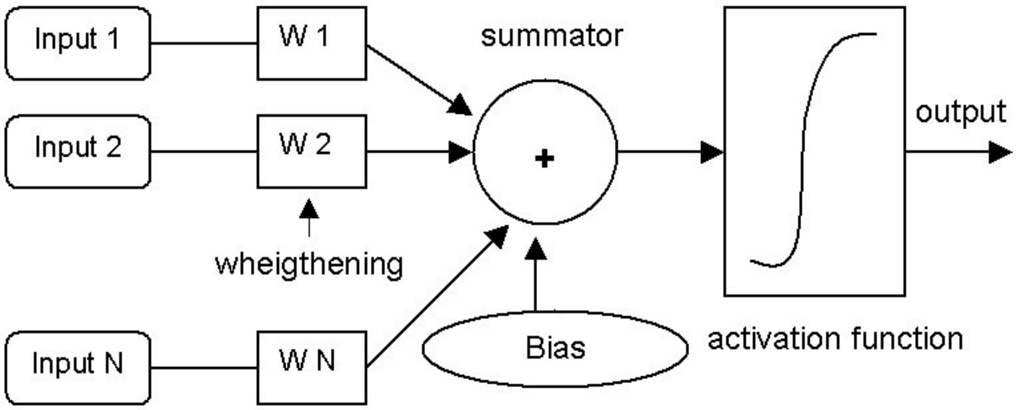

Figure 8. *The general artificial neuron.*

In principle, a general artificial neuron is some simple electronic device, not able to do much. The value of the artificial neuron becomes important when there are many neurons connected together. Such cases are called Artificial Neural Networks, ANNs. These systems can be built in many different ways but the most efficient way to describe them is to describe the topology. As the literature describes, there are many different topologies but there are at least 2 principles to be mentioned: the connecting complexity and the information carrier material. This can be seen in **Figure 9**.

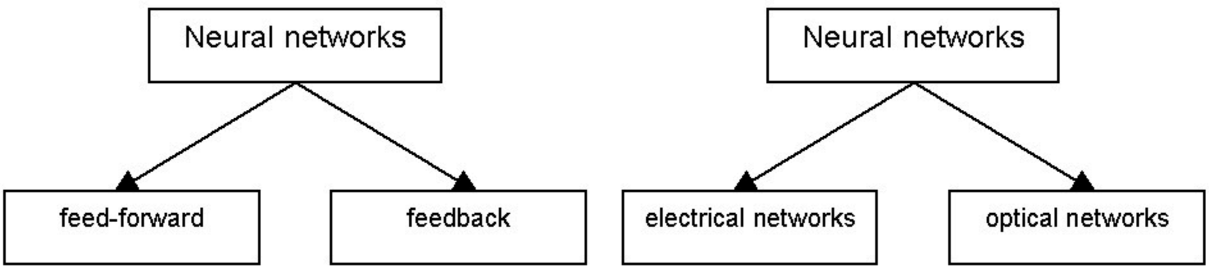

Figure 9. *The artificial neuron's generalisation principles.*

As we can see from **Figure 9**, the ANNs can be divided into feed-forward networks and recurrent/feedback networks. Also, we can see, that the ANNs can be realised as electrical circuits or as optical systems (Boone, 1998). The information processing's complexity increases rapidly when more neuronal layers, called hidden layers are added to the network. The meaning of the input, hidden and output layers is described on **Figure 10**.

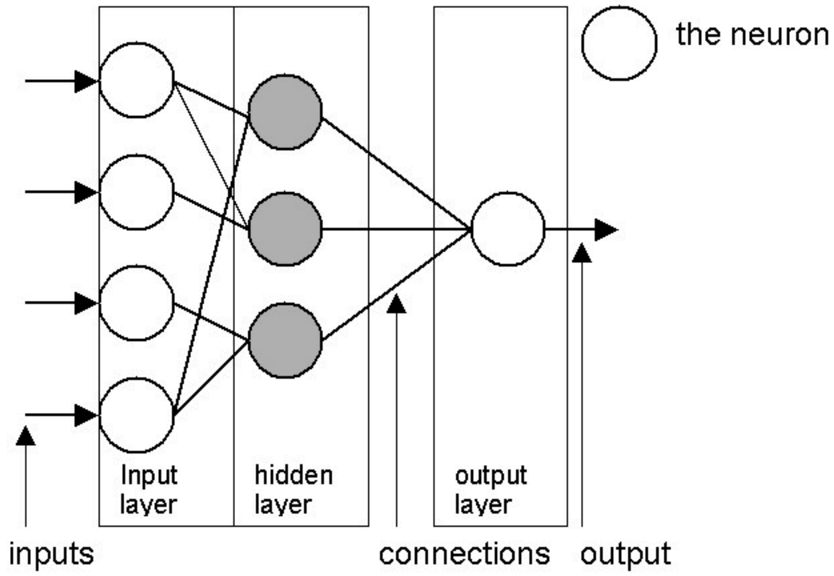

Figure 10. *The layers of the artificial neuron network.*

More detailed information about the ANN topology can be found from the articles written by (Guresen and Kayakutlu, 2011, Fekiac et al., 2011, Vainbrand and Ginosar, 2010). An article by (Guresen and Kayakutlu, 2011) describe the definition of artificial neural networks with comparison to other networks. An article by (Fekiac et al., 2011) describes ANN network topology in evolutionary computation. The article by (Vainbrand and Ginosar, 2010) describes the usage of the network on chip (NoC). The most complete picture about the ANN-problem can be found in a book by (Teodorescu et al., 1988) what includes articles written by many different authors and therefore covers the topic on many different complexity levels, from transistor circuits to big systems. Last but not least, the recurrent ANNs have some resemblance with associative memory, so there is much to study (Russell and Norvig, 2016).

Books to be recommended:

Theoretical Models In Biology, The origin of life, the immune system and the brain,
Oxford Science Publications, 1997,
Glenn W. Rowe, ISBN: 0 19 8596871

Neural Network Fundamentals With Graphs, Algorithms, And Applications,
N.K.Bose and P.Liang, 1996
McGraw-Hill, ISBN: 0-07-006618-3

6.2.4 THE ARTIFICIAL INTELLIGENCE

There are 2 aspects to describe the history of the AI. One aspect starts from mentioning the antique philosophers and kinky medival age inventions. The other aspect starts from mentioning the John McCarthy's 1956 workshop where the AI came from (Russell and Norvig, 2016). Within years of development the AI gathered into himself subfields like:

- Heuristic search
- Computer vision
- Natural language processing
- Artificial neural networks
- Fuzzy logic
- Machine learning
- Expert systems
- Knowledge representation and reasoning

Maybe one of the earliest AI devices was "the Colossus", a computer built on vacume tubes in 1943 (Russell and Norvig, 2016). Later years are full of electronic devices, PCs and software – different aspects of the AI. Detailed information about the usage of AI in medicine can be found from articles by (Gonzalez et al., 2020, Park et al., 2019, Jiang et al., 2017, Simm, 2020).

6.2.5 META – ANALYSIS

Well, You have the Great Idea ! You want to do it. The only problem is that there is no "such" literature and you have to search for it. In order to make a comprehensive overview you have to refer to all kind of literature. Writing such a big analysis is a great challenge for everyone, problems everythere. All problems can't be foreseen but some ideas can be given. For example, try to present your data in a easily understandable manner when you have hundreds of articles, all having different pictures / graphs. Because of that, it is recommendable to have ideas about statistics, math analysis and other topics. There is also a lot of literature what describes the details of Meta – Analysis (Peacock and Peacock, 2012, Seidler et al., 2019, Haidich, 2010).

6.3 THE SIGNAL PROCESSING

6.3.1. INTRODUCTION

For the researcher or engineer, working with the baby monitor's electronics and software, there are 3 aspects to keep in mind: analog signal processing, digital signal processing and the transformation methods. The signal processing is a method, where the original signal is conditioned by applying some kind of principle to it (like averaging, amplification) either in time and/or frequency domain, in order to change or alter the signal in some kind of way. The signal processing can be done either by using electronic components (analog signal processing) or by using computational methods like microcontrollers (digital signal processing). The processing can be very simple or very complicated and therefore it always takes time to think, how to process the signal. Also, there are 2 important aspects to keep in mind: signal processing in time domain and signal processing in frequency domain. Possibly the most difficult aspect to understand is the understanding of the transformation methods (like Fourier transformation, Hilbert transformation and so on). In order to describe the introduction in a more detailed way, let's have a look on **Figure 11**.

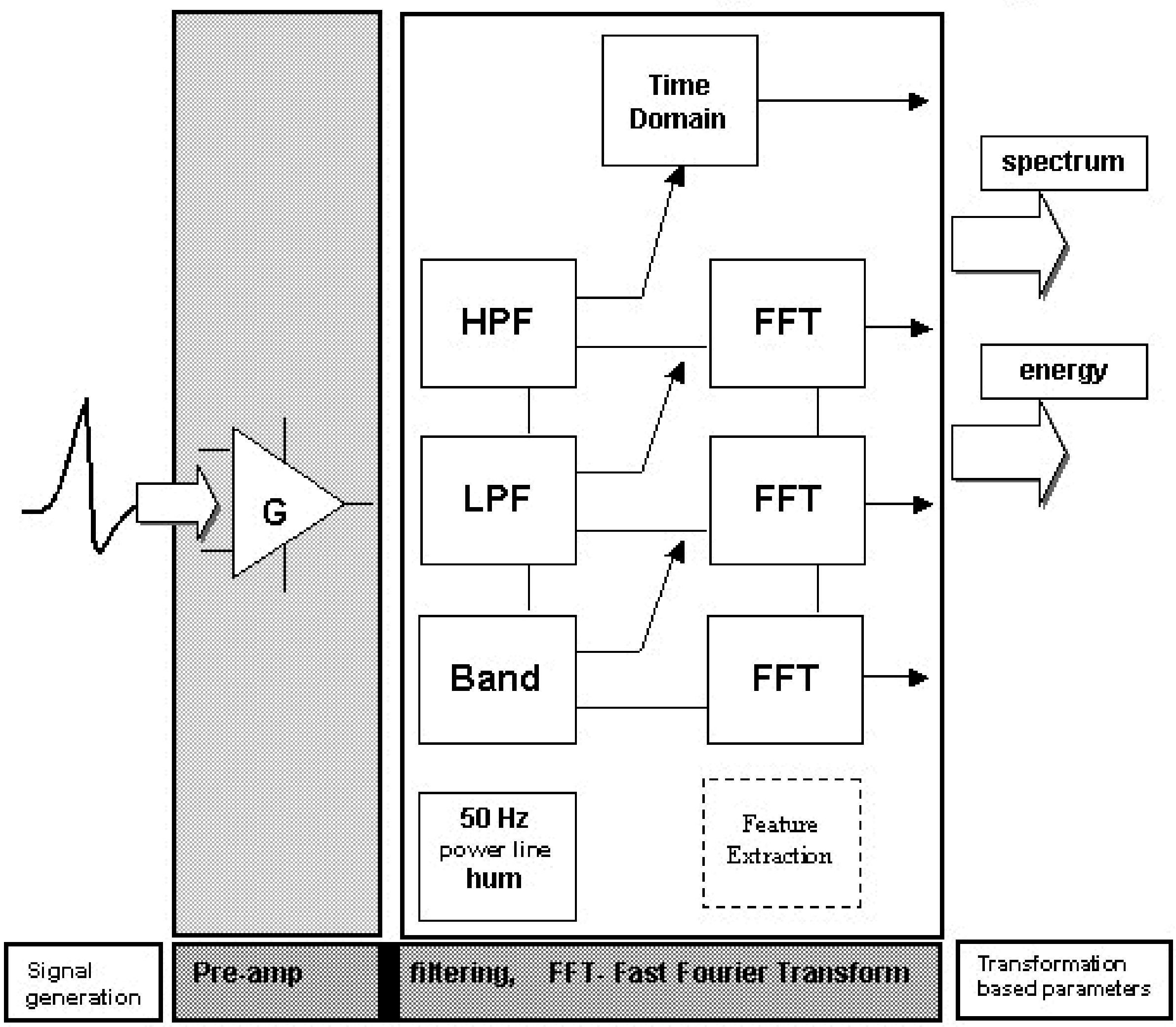

***Figure 11**. ECG signal processing.*

Figure 11 has a very specific name – “ECG signal processing”. Because of this name we expect that there is a patient who’s heart generates a electrical activity signal – the ECG signal. It is expected that a box called **“signal generation”** describes it. As the ECG signal reaches to the electrodes, it moves along until it reaches the pre-amplifier. The pre-amplifier is an amplifier what amplifies the signal without distorting it. Because of this pre-amplification the signal becomes conditionable and now it is possible to apply analogue and digital signal processing methods. Boxes named **“HPF”**, **“LPF”** and **“Band”** describe high-pass filter, low-pass filter and band-pass filter respectively. These filters can be realised either with analog or digital filtering methods. A box called **“50 Hz power line hum”** describes a filter what removes the power line hum what usually appears on 50 Hz. A box called **“Feature Extraction”** describes some kind of special filtering circuit or software algorithm what detects some kind of specific feature. The box called **“FFT”** describes Fast Fourier Transformation, a method what makes it possible to describe the signal in frequency domain. The box named **“time domain”** describes the signal after high-pass, low-pass and band-pass time domain filtering. A box called **“transformation based methods”** refers to the usage of spectrum and energy computing. More detailed information can be found from electronics articles (Borowska, 2015, Ibrahimu, 2010) and biomedical engineering books (Bronzino, 2006, Northrop, 2004).

6.3.2. ANALOG SIGNAL PROCESSING

Analog signal processing is a very old signal processing method and includes many different principles. Different articles point the start of signal processing into different ages and places but certainly there is some truth in the IEEE Signal Processing Society’s document, what places the birth of signal processing into 1948 with describing the work of the Proffesional Group on Audio of the Institute of Radio Engineers (Nebeker, 1998). The invention of the transistor demanded the birth of the field named signal processing. Today there are many books (Heinrichsen, 1996, Northrop, 2004) what describe the usage of analog electronics and analog signal processing. This sub chapter describes only some principles of analog signal processing what can be used for the designing of the baby monitor. Most of all, here we mention the amplification and filtering processes.

Signal amplification

Almost every biosignal needs some amplification. Because of that knowledge about the amplifiers is essential. The history of the amplifiers is well documented and tells us that the first operational amplifier ideas came from Harry Black in 1934 and the graphical methods representing the operational amplifier’s stability come from H.W. Bode in 1945 (Mancini, 2002). Today there are 2 different possibilites how to build an amplifier: to design the amplifier and soldier it or use the amplifier chip and add some resistors and capacitors to it. Different situations need different approaches and because of that we have a look on operational amplifer circuits. The operational amplifier is a mid-level component, leaving the details for the designer and specific enough to be unambiguously understood. It should be mentioned that understanding the operational amplifier’s working principles requires only some mathematics – on a first level basis the knowledge about the Ohm’s Law (**Equation 1**) and the Kirchoff’s Laws (**Equations 2 & 3**) is good enough. Also, the reader should have understandings about the voltage divider’s rule because the voltage divider’s rule can be used to calculate the not loaded amplifier circuit’s output voltage. This sub-chapter describes

4 different usages of operational amplifiers: the non-inverting amplifier, the inverting amplifier, the differential amplifier and the instrumentation amplifier. More data about operational amplifier's design can be found from the literature (Mancini, 2002).

The basic equations used to describe the operational amplifier:

The Ohm's Law $I = U / R$ **Equation 1**

I is the current in the circuit
U is voltage
R is the resistance

The Kirhoff's Voltage Law $\sum V_{sources} = \sum V_{drops}$ **Equation 2**

The sum of the voltage drops in a series circuit equals the sum of the voltage sources.

The Kirhoff's Current Law $\sum I_{in} = \sum I_{out}$ **Equation 3**

The sum of the currents entering the junction equals the sum of the currents leaving the junction.

Some amplifier types the baby monitor's designer may need to know:

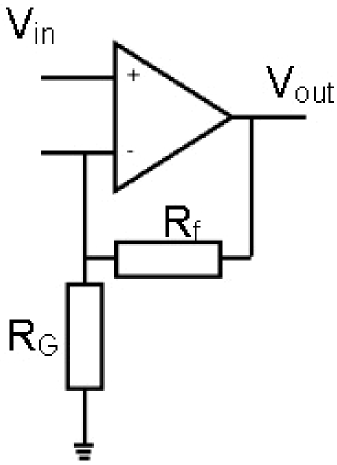

Figure 12. *The non-inverting amplifier.*

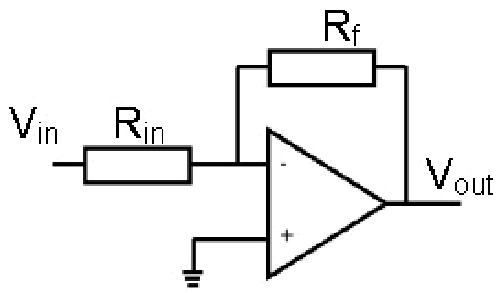

Figure 13. *The inverting amplifier.*

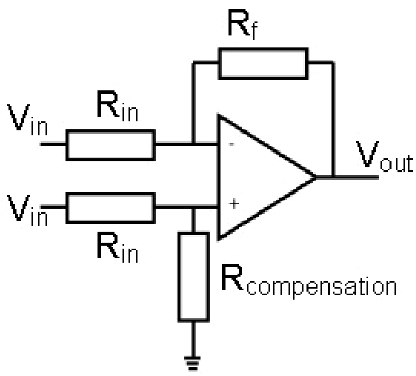

Figure 14. *The differential amplifier.*

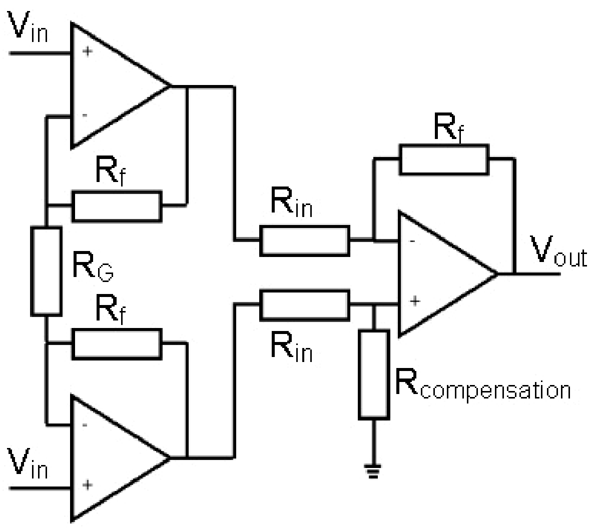

Figure 15. *The Instrumentation amplifier.*

Here:
R_f – feedback resistor
R_G – gain resistor

The non-inverting amplifier

The non-inverting amplifier is an amplifier what amplifies the input signal so what the output signal is an amplified copy of the input signal. The amplification depends on the feedback resistor's and input resistor's ratio, as it can be seen on **Figure 12**. This is the easiest type of amplifier to design.

The inverting amplifier

This amplifier is an amplifer where the the output signal is an amplified copy of the input signal but the signal itself is inverted. The operational amplifier based inverting amplifier circuit can be seen on **Figure 13**. The inverting amplifier is very similiar to the non-inverting amplifier – within the easiest case the amplification depends only on the usage of 2 resistors.

The differential amplifier

This amplifier is an amplifer what the difference signal between the inputs. This amplifier can be useful when the signal is covered with noise and small in amplitude. The differential amplifeir circuit is shown on **Figure 14**. Because the differential amplifier uses 2 inputs, it also needs 4 resistors. Here, and also on other operational amplifier related circuits, as shown on **Figures 12-15**, we expect that the amplifier is an idealized operational amplifier and the usage of extra output resistors is not neccesarry. In reality the operational amplifier's output may need a special matching resistor and a (parallel) filtering capacitor.

The instrumentation amplifier

This amplifier is the most often used amplifier among the medical devices. The design expects that there are 2 buffering amplifiers and the output of these buffering amplifiers is used to feed the differential amplifier. The operational amplifier based instrumentation amplifier circuit is shown on **Figure 15**. Here are some reasons why the instrumentational amplifer is used in biomedical engineering:

- Very accurate, very stable
- High input impedance
- Low output impedance
- Very high common mode rejection ratio, CMRR

More data about the operational amplifier based circuits can be found from the literature, for example (Green et al., 2018, Northrop, 2004).

Signal filtering

Signal processing almost always needs some filtering. According to the popularity of usage, the analog signal processing uses most often the Low Pass Filter, the High Pass Filter and the Band pass filter. These filters can be built as passive circuits, but also as active circuits when they are connected to the amplifying circuit. Usually the filtering circuits are made of the usage of the resistors, the capacitors and the calculation of the corner frequency. The inductors are not so often used but they can't be neglected.

The calculation of the corner frequency usually begins by defining how the capacitances and inductances are related to the complex impedances. Usually 2 different ways are used to define the "complex" nature, either by using the s-plane or by using the jω plane.

The complex impedance according to the s-plane (generalized concept)

- $Z_L = sL$ **Equation 4**, the complex inductance on the s plane
- $Z_C = 1/sC$ **Equation 5**, the complex capacitance on the s plane
- $S = \sigma + j\omega$ **Equation 6**, the complex impedance on the s plane,

  where σ is the Neper frequency in Nepers in second
  ω is the frequency in radians per second
  j is the imaginary unit.

The complex impedance according to the $j\omega$ plane

- $Z = R + jX$ **Equation 7**, the complex impedance according to the $j\omega$ plane,

  where Z is the complex impedance
  R is the resistance in Ohms, the real part
  jX is the reactance, the imaginary part

- $\theta = \tan^{-1}((X_L - X_C) / R)$ **Equation 8**, the phase arc

  where Z_L is the complex inductance $Z_L = j\omega L$
  Z_C is the complex capacitance $Z_C = 1 / j\omega C$
  R is the resistance

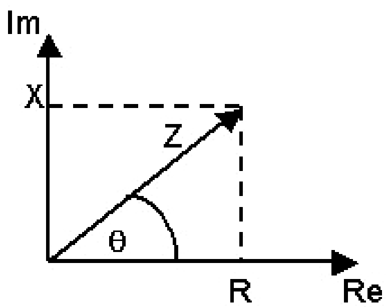

***Figure 16**. Graphical representation of the impedance as a complex exponential.*

Here **Equation 7** describes the impedance as a complex exponential, as shown on **Figure 16**. As we can see, the **Figure 16** also describes the arc θ (**Equation 8**), a parameter used to describe the phase. Sometimes the AC circuits are described by using the Euler's equation, as seen on **Equation 9**.

- $e^{j\omega t} = \cos \omega t + j \sin \omega t$ **Equation 9**, the Euler's equation

The filter's transfer function can be described as a relation of polynomials (**Equation 10**):

$$H(s) = \frac{a_m s^m + a_{m-1} s^{m-1} + \ldots + a_1 s + a_0}{b_n s^n + b_{n-1} s^{n-1} + \ldots + b_1 s + b_0} \quad \textbf{Equation 10}$$

Where: the degree of the denominator is the order of the filter, the higher the order of the filter, the more sudden the filter's cut-off.

The solutions of the equation of the denominator describes the poles and the solutions of the numerator describes the zeros.

The analog filtering process usually includes some of the following filters: the Low Pass Filter, the High Pass Filter, the Band Pass Filter and different variations of them. Here these filters are analyzed according to the circuits used and the frequency plot they generate. The **A** letter indicates the amplitude and here **0,7 A** indicates amplitude with the – 3 dB ripple.

Low Pass Filter

This filter, as seen on **Figure 17**, made of resistance R and capacitance C, allows low frequencies to pass and surpresses the high frequencies. Here the filter's time responce is given by a simple **Equation 11**, τ = **RC**. The cutoff frequency, sometimes named corner frequency, $\mathbf{f_c}$, of the filter is given by **Equation 12**, where $\mathbf{f_c = 1 / 2\pi\tau = 1 / 2\pi RC}$.

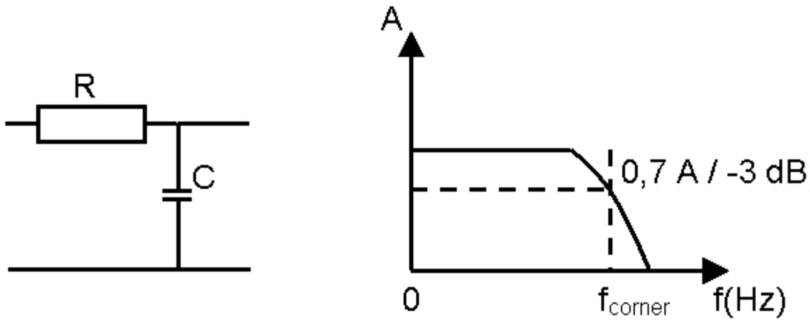

Figure 17. *The LPF circuit and frequency response.*

High Pass Filter

This filter, as seen on **Figure 18**, made of resistance R and capacitance C, allows high frequencies to pass and surpresses the low frequencies.

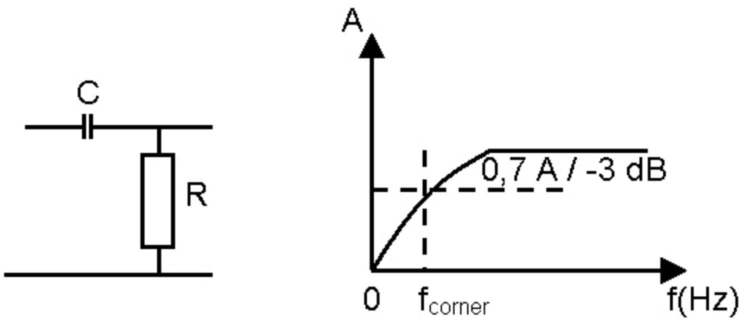

Figure 18. *The HPF circuit and frequency response.*

Band Pass Filter

This filter, as seen on **Figure 19**, is a combination of 2 filters, the Low Pass Filter and the High Pass Filter. The **f** letters on the **Figure 19** indicate the low cut-off frequency, the centre frequency and the high cut-off frequency.

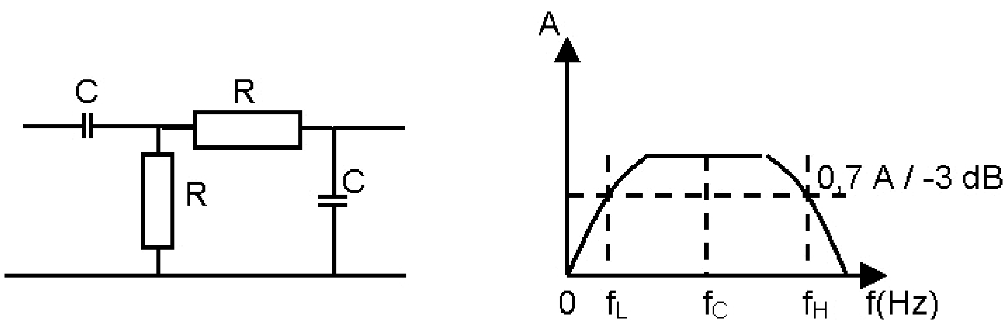

Figure 19. *The Band Pass Filter circuit and frequency response.*

6.3.3. DIGITAL SIGNAL PROCESSING

Digital signal processing is an essential figure of the modern medical device. Scientists usually like the digital signal processing (DSP) methods because the process is completely virtual – everything is done inside a PC or microcontroller and the results can be highly selective and easy to alter. The DSP history dates back to 1970 when a group of scientists gathered on the International Seminar on Digital Processing of Analog Signals (Nebeker, 1998). The digital signal processing as a subfield can be divided into 3 big parts: the generation of the digital signal, digital signal processing and the generation of the analog signal. The generation of the digital signal is a process where the analog signal in continous time form is converted into binary values, zeros and ones. The generation of the digital signal is described on **Figure 20**.

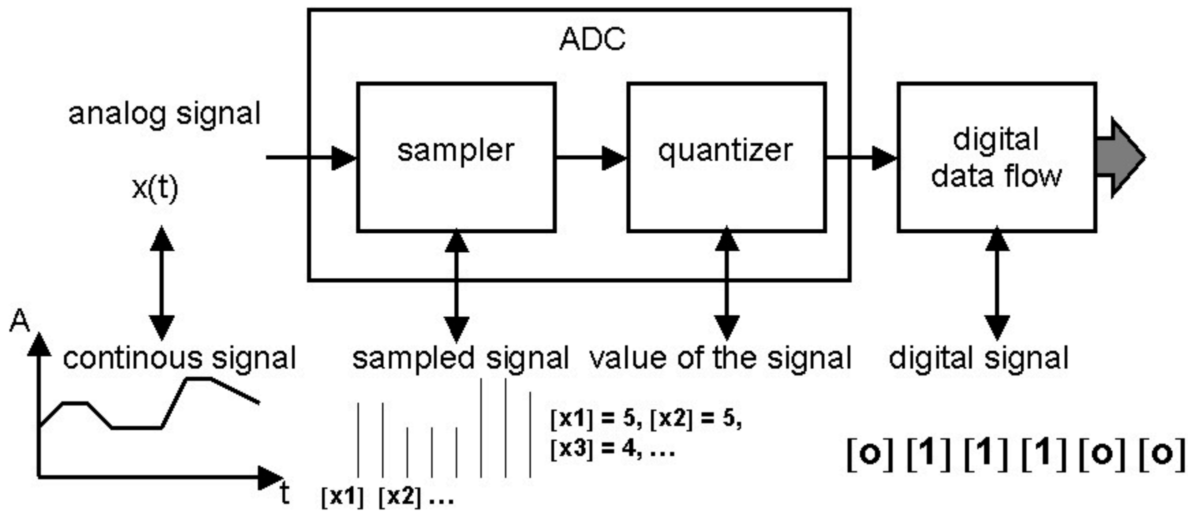

***Figure 20**. The generation of the digital signal.*

As we can see from **Figure 20**, the generation of the digital signal includes 2 big processes, the sampling and the quantization. Both of these processes are implemented inside the analog-to-digital converter, the ADC and the output of the ADC is a digital data stream. Here sampling means that the original signal is recorded after every certain time event, dependant of the sampling frequency. The sampling frequency is determined with the Nyquist criteria, which means that the sampling frequency has to be at least 2 times the original analog signal bandwith. Quantization means that every sample has been given a value in numbers. More data about the usage of the ADC converters can be found either from books describing the theory (Manolakis et al., 2005, Smith, 1999) or from ADC chip's data sheets (ADC1175 datasheet, 2013).

The digital signal processing as a subfield is full of mathematics. The scientists search for newer and better functions what to apply. The DSP methods are usually applied to ASICs, FPGAs, micronontrollers and processors.There many reasons why different DSP methods are used but here, inside the baby monitor's world filtering is essential. The DSP filtering can be realized according to many principles but in general DSP filters are divided into 2 subfields: the Infinite Impluse Response (IIR) filters and the Finite Impulse Resonse (FIR) filters.

The generation of the analog signal is a process where the digital data stream is converted into continous analog signal. For example, some kind of bit stream is converted into audio.

Some examples of the usage of the digital signal processing methods for the ECG.

The field of DSP is very wide and therefore only some books and articles are mentioned. For a start, there are books about biomedical/bioelectrical signal processing (Bruce, 2001, Sörnmo & Laguna, 2005) and articles (Zahoor & Naseem, 2017). Also, there are books what describe the filtering technique and offer some laboratory works with it(Tompkins, 1993). Considering the complexity of the DSP based ECG signal conditioning, this book offers some words – just in case you have to make a search:

Baseline wander, powerline interference, Heart Rate Variability (HRV), QRS detection, polynomial fitting, ECG, filtering, time domain filters, frequency domain filters, adaptive filter, frequency spectrum

Some IIR based methods

Implementing IIR Digital Filters
(A. Palacherla, 1997)

ECG Digital Filters, 2014
(Application Note 6906, Maxim Integrated)

Supression of Noise in ECG Signal Using Low pass IIR Filters (Choudhary & Narwaria)

Some FIR based methods

FIR Filter Design Techniques
(Arojit Roychowdhury, 2002)

Novel Signal Processing Methods for Exercise ECG
(Willi Kaiser and Martin Findeis, 2000)

Designing a Linear FIR filter
(Darsena & Agrawal, 2016)

Also, it is useful to compare different methods(FIR vs IIR), for example just like by (Seema rani et al., 2011, Sreedevi & Anuradha, 2016, Wadhwani & Yadav, 2011).

6.3.4. THE TRANSFORMATION METHODS

This is it! You have to transform the signal into something else and you are searching for ideas, what to do. Mathematics is full of possibilities what to do but sometimes things can be difficult, not a single word/idea. Nothing to do... Sometimes it helps some people when they see some kind of algorithm what to do. Here a “slice of cake”, **Figure 21**, is made by the beauty of the integrals. If it helps, play with it but at your own risk!

On **Figure 21** only some most common transformation based methods are mentioned. However, this is not all. There are also thousands of possibilities how to compute different entropies, energy, spectrum and other things. Because the world literature list is ever so growing, here only some books and articles are mentioned. Just to give the idea what they talk about.

The general picture:

Fundamentals of Signal Processing,
R. Baraniuk et al., Rice University, Huoston, Texas, 2014

Mathematical Methods and Algorithms for Signal Processing,
T.K. Moon & W.C. Stirling, Prentice Hall, 1999
ISBN: 0-201-36186-8

Some specific books:

Bioelectrical Signal Processing in Cardiac and Neurological Applications,
L. Sörnmo & P. Laguna, Elsevier Academic Press 2005,
ISBN: 0-12-437552-9

Biomedical Signal Processing and Signal Modeling,
E.N.Bruce, John Wiley & Sons, Inc, 2001,
ISBN: 0-471-34540-7

Biomedical Signal Analysis, A Case –Study Approach,
R.M. Rangayyan, John Wiley & Sons, Inc, 2002
ISBN: 0-471-20811-6

Some articles:

Entropy-Based Algorithms in the Analysis of Biomedical Signals,
M. Borowska, Studies In Logic, Grammar and Rhetoric 43 (56), 2015
DOI: 10.1515/slgr-2015-0039

Wavelets and Signal Processing,
O. Rioul and M. Vetterli, IEEE SP Magazine, October 1991

The Hilbert Transform,
M. Johansson, Master Thesis, Supervisor B. Nilsson, Växjö University

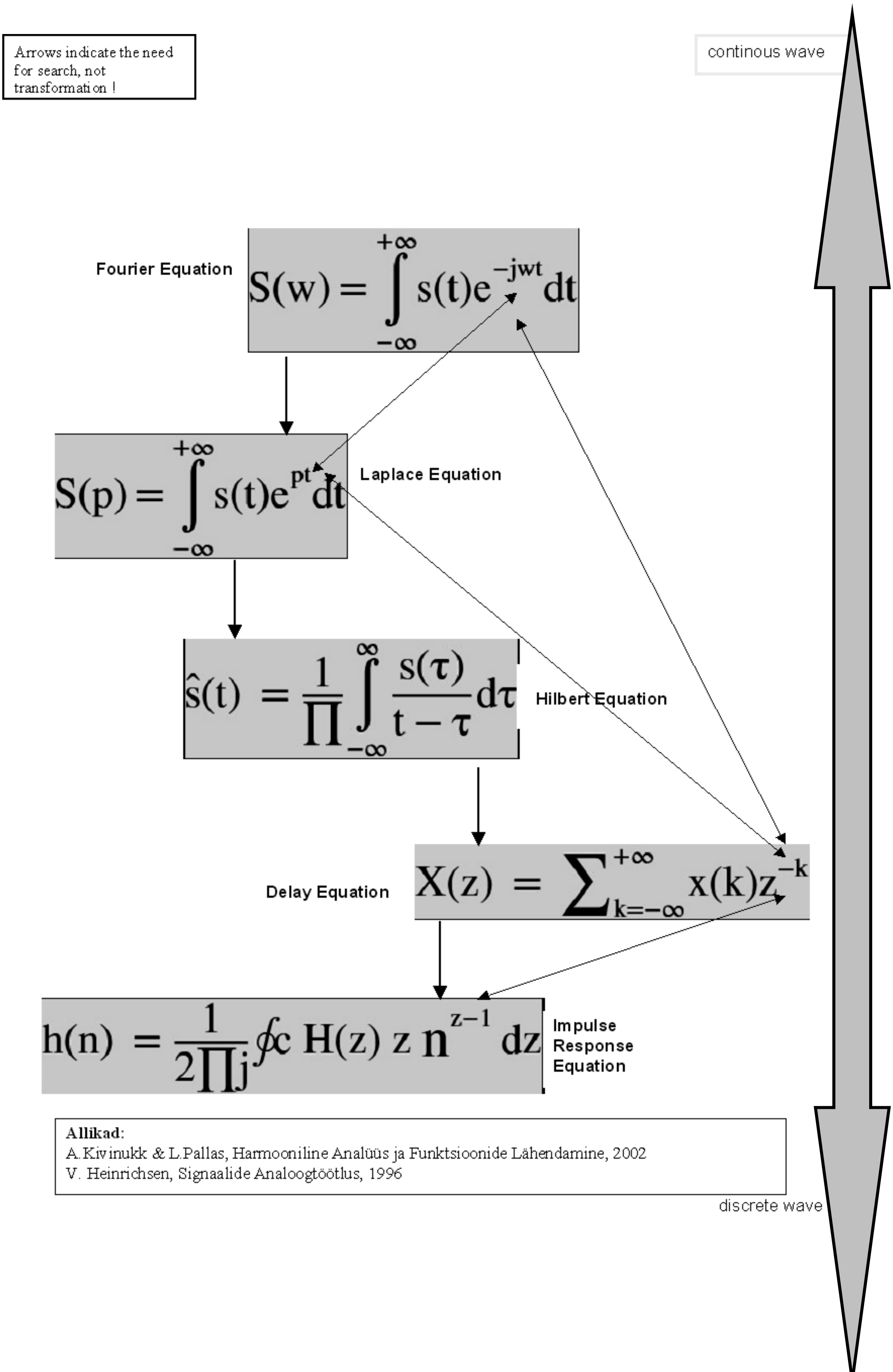

Figure 21*. Some Equations You Might Like…*

References

F. Baig et al., 2011
Design Model of Fuzzy Logic Medical Diagnosis Control System,
International Journal on Computer Science and Engineering (IJCSE), 2011,
Vol. 3, No. 5, ISSN: 0975-3397

B.G. Boone, 1998
Signal Processing Using Optics,
Fundamentals, Devices, Architectures, and Applications,
Oxford University Press, ISBN: 0-19-508424-1

M. Borowska, 2015
Entropy-Based Algorithms in the Analysis of Biomedical Signals,
Studies in Logic, Grammar and Rhetoric, 43(56), 2015,
DOI: 10.1515/slgr-2015-0039, ISBN: 978-83-7431-464-0

J.D. Bronzino, 2006
Medical Devices and Systems,
The Electrical Engineering Series,
ISBN: 0-8493-2122-0

E.N. Bruce, 2001
Biomedical Signal Processing and Signal Modelling,
Wiley Series in Telecommunications and Signal Processing,
ISBN: 0-471-34540-7

M. Choudhary & R.P. Narwaria, 2012
Supression of Noise in ECG Signal Using Low pass IIR Filters,
International Journal of Electronics and Computer Science Engineering,
Vol. 1, No. 4, ISSN: 2277-1956

L. Darsena & H. Agrawal, 2016
Designing a Linear FIR filter,
International Journal of Science, Engineering and Technology Research (IJSETR),
Vol. 5, Issue 1, 2016

A.D. Dongare et al., 2012
Introduction to Artificial Neural Network,
International Journal of Engineering and Innovative Technology (IJEIT),
Vol. 2., Issue 1, 2012, ISSN: 2277-3754

J. Fekiac et al., 2011
A Review of Methods for Encoding Neural Network Topologies in Evolutionary Computation,
Proceedings 25 th European Conference on Modelling and Simulation , ECMS,
Krakow, Poland, June 7 th- 10th
ISBN: 978-0-9564944-2-9

T. Glover and K. Mitchell, 2002
An introduction to biostatistics, McGraw-Hill

G.-Gonzalez et al., 2020
Artificial Intelligence in Medicine and Healthcare: a review and classification of current and near-future applications and their ethical and social impact.
arXiv:2001.09778,2020.

T. Green et al., 2018
Analog Engineer’s Circuit Cookbook: Op Amps, First Edition, SLYY137-03/2018
Texas Instruments

S. I. Grossman and J. E. Turner, 1974
Mathematics for the Biological Sciences,
Macmillan Publishing Co., Inc / Collier Macmillan Publishers
ISBN: 0-02-348330-X

E. Guresen and G. Kayakutlu, 2011
Definition of artificial neural networks with comparison to other networks,
Procedia Computer Science, 3, 2011, pp. 426-433

A.-B. Haidich, 2010
Meta-analysis in medical research, Review article
Hippokratia 2010, 14, Suppl. 1, pp. 29-37.

J. Han, 2002
How Can Data Mining Help Bio-Data Analysis ?,
Workshop on Data Mining in Bioinformatics

V. Heinrichsen, 1996
Signaalide Analoogtöötlus,
Tallinn University of Technology, Institute of Radio and Communications,

M. Hellemann, 2001
Fuzzy Logic Introduction,
German Aerospace Center

P. Holmberg et. al., 2002, tõlkinud Ü. Ugaste, 2007
Santorius. Biotieteiden fysiikka,
ISBN: 978-9985-57-877-3

M.I. Ibrahimy, 2010
Biomedical Signal Processing and Applications,
Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management,
Dhaka, Bangladesh, January 9-10, 2010

M.S. Islam et al., 2018
A Systematic Review on Healthcare Analytics: Application and Theoretical Perspective of Data Mining,
Healthcare 2018, 6, 54

F. Jiang et al., 2017
Artificial intelligence in healthcare: past, present and future,
Stroke and Vascular Neurology, 2017, 2, e000101, doi: 10.1136/svn-2017-000101

A. Jõgi, 2000
Tõenäosusteooria, 1. osa, Tallinna Tehnikaülikool, Matemaatikainstituut,
ISBN: 9985-59-167-4

W. Kaiser and M. Findeis, 2000
Novel Signal Processing Methods for Exercise ECG,
International Journal of Bioelectromagnetism (IJBEM),
Vol. 2, No. 1, pp. 71-78

N.N. Karnik et al., 1999
Type-2 Fuzzy Logic Systems,
IEEE Transactions on Fuzzy Systems, 1999, Vol. 7, No. 6

R. Kiley, 1999
Medical Information on the Internet, A Guide for Health Professionals,
ISBN: 0 443 06194 7

R. Küttner and V. Jutman, 2007
Teadmuspõhised süsteemid masinaehituses,
TTÜ, 2007, ISBN: 978-9985-59-744-6

Ü. Maiväli, 2015
Interpreting Biomedical Science, Experiment, Evidence and Belief,
ISBN: 978-0-12-418689-7

R. Mancini, 2002
Op Amps For Everyone, Design Reference,
Advanced Analog Products, August 2002, SLOD006B, Texas Instruments

D.G. Manolakis et al., 2005
Statistical and Adaptive Signal Processing,
Spectral Estimation, Signal Modeling, Adaptive Filtering, and Array Processing,
Artech House, Inc, ISBN: 1-58053-610-7

S. Michelson and T. Schofield, 1996
The Biostatistics Cookbook. The most user-friendly guide for the bio/medical scientist,
Kluwer Academic Publishers, ISBN: 0-7923-3884-7

F. Nebeker, 1998
Fifty Years of Signal Processing: The IEEE Signal Processing Society and its Technologies 1948-1998

R.B. Northrop, 2004
Analysis and Application of Analog Electronic Circuits to Biomedical Instrumentation,
CRC Press
ISBN: 0-8493-2143-3

A. Orooji et al., 2019
A Comparison Between Fuzzy Type-1 and Type-2 Systems in Medical Decision Making: A Systematic Review,
Crescent Journal of Medical and Biological Sciences, 2019, Vol. 6, No. 3, pp. 246-252
EISSN: 2148-9696

S.H. Park et al., 2019
Ethical challenges regarding artificial intelligence in medicine from the perspective of scientific editing and peer review,
Sci Ed. 2019, 6(2), pp. 91-98, eISSN: 2288-7474

J. L. Peacock and P. J. Peacock, 2012
Oxford Handbook of Medical Statistics,
Oxford University Press, ISBN: 978-0-19-955128-6

A. Roychowdhury, 2002
FIR Filter Design Techniques,
M.Tech credit seminar report, Electronic Systems Group, EE Dept, IIT Bombay

S.J. Russell and P. Norvig, 2016
Artificial Intelligence, A Modern Approach, Third Edition,
Prentice Hall Series, ISBN: 10: 1292153962

Seema rani et al., 2011
Comparative study of FIR and IIR filters for the removal of Baseline noises from ECG signal,
International Journal of Computer Science and Information Technologies,
Vol. 2(3), 2011, pp. 1105-1108, ISSN: 0975-9646

A.L. Seidler et al., 2019
A guide to prospective meta.analysis,
BMJ 2019,367, 15342

K. Simm, 2020
Tehisintellekt meditsiinis-eetilised ja ühiskondlikud aspektid,
Eesti Arst, 2020, 99(6), pp. 362-367

S.W. Smith, 1999
The Scientist and Engineer's Guide to Digital Signal Processing,
California Technical Publishing, ISBN: 0-9660176-6-8

G. Sreedevi & B. Anuradha, 2016
Using of FIR and IIR Filters for Noise Removal from ECG Signal: A Perfomance Analysis,
International Journal of Electronics and Communication Engineering and Technology (IJECET) Vol. 7, Issue 4, July-August 2016, pp. 91-99

L. Sörnmo & P. Laguna, 2005
Bioelectrical Signal Processing In Cardiac and Neurological Applications,
Elsevier Academic Press, ISBN: 0-12-437552-9

H.-N. Teodorescu, 1988
Fuzzy and NeuroFuzzy Systems in Medicine,
CRC Press, 1998, ISBN: 0849398061, 9780849398063

W.J. Tompkins, 1993
Biomedical Digital Signal Processing, C-Language Examples and Laboratory Experiments for the IBM PC,
Prentice Hall, 1993, ISBN: 0-13-067216-5

D. Vainbrand and R. Ginosar, 2010
Network on Chip Architectures for Neural Networks,
2010 Fourth ACM/IEEE International Symposium on Networks-on-Chip

L.P.J. Veelenturf, 1995
Analysis and Applications of Artificial Neural Networks,
Prentice Hall International, ISBN: 0-13-489832-X

J. Vedru and J. Pruulmann, 2012
Elussüsteemid, Tartu 2012
ISBN: 978-99496-23-352-6

S. Zahoor & S. Naseem, 2017
Design and implementation of an efficient FIR digital filter,
Cogent Engineering, Electrical & Electronic Engineering, Research Article,
2017, 4, 1323373

S.L. Zeger et al., 2004
On Time Series Analysis of Public Health and Biomedical Data,
Johns Hopkins University, Dept. of Biostatistics Working Papers

A.K. Wadhwani & M. Yadav, 2011
Filtration of ECG signal By Using Various Filter,
International Journal of Modern Engineering Research(IJMER),
Vol. 1, Issue 2, pp. 658-661, ISSN: 2249-6645

Data sheets:

ADC1175
www.ti.com

ECG Digital Filters, 2014
Application Note 6906, Maxim Integrated

Implementing IIR Digital Filters
A. Palacherla, 1997

APPENDIX 1 THE EVERYDAY ELECTRONICS

The chapters described how to design the baby monitors and what kind of technical tricks are used. Not all of this knowledge comes with the same weightning, sometimes you have to choose what kind of trick or treat to use, why and what comes around with it. This appendix describes existing baby monitors what You can buy from a shop – how they look like. The photos are made in order to give the impression You might get. In the end, You have to design the device by yourself, so You know best what kind of circuits to use. All the data comes from the instruction sheets supported with the device itself.

I had a wish to measure the electric fields around the devices and include the data here, within this appendix but had no measurement equippment, so You have to measure it by yourself.

Simply Care by Babymoov, France

Baby unit
Power on/Battery low indicator
Power on-off and VOX switch
Channel switch
Transmit indicator
Micro usb mains connector
Microphone

Parent unit
Power on/Battery low indicator
Power on/off and volume control
Channel switch
Visual LED alarm
Micro usb mains connector
Speaker

Figure 1. *The outside of the baby monitor.*

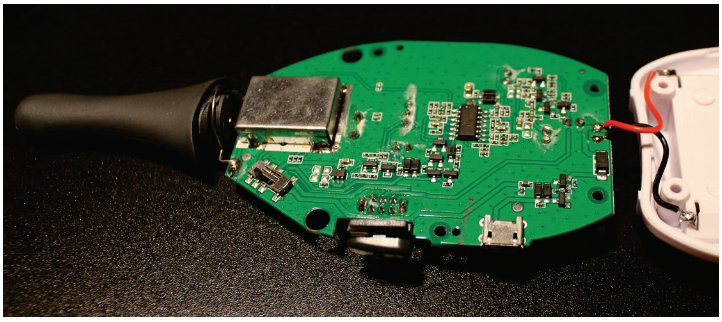

Figure 2. *The inside of the baby monitor.*

Works with AAA batteries or
on mains (5V AC adapter)

Range 300 m open space

2 channels

Standards:
EMC EN 301 489-1 V1.9.2
EN 301 489-3 V1.6.1

Radio EN 300 220-1 V2.4.1
EN 300 220-2 V2.4.1

Health EN 62479: 2010
Safety EN 60065:2014

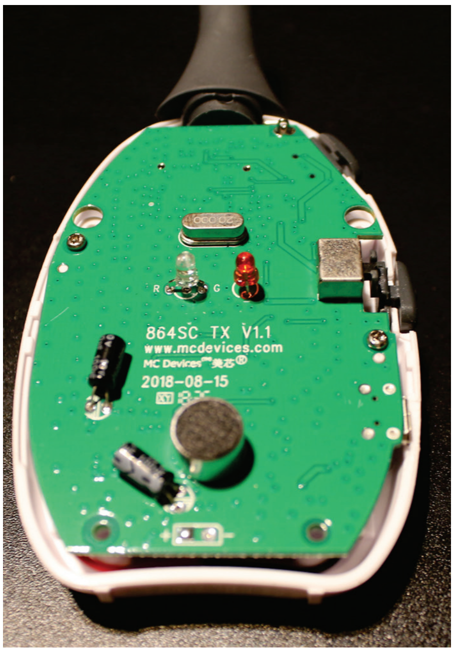

Figure 3. *The inside of the baby monitor.*

Beurer babycare by Beurer GmbH, Germany

Baby unit
Size: 7 x 6,9 x 4,3 cm
Mass: 48 grams
Adapter: 6 V DC / 450 mA

Parent unit
Size: 6,7 x 10,1 x 4,3 cm
Mass: 100 grams
Adapter: 6 V DC / 450 mA

DECT technology
120 channels
transmission frequency 1.8 GHz
Transmission power max 22,20 dBM

***Figure 1**. The outside of the baby monitor.*

works about 10 hours
works on batteries or AC adapter

Range 300 m open space
Leaving the range warning

Place the babymonitor 1,5 m from the baby in order to minimize the electric field

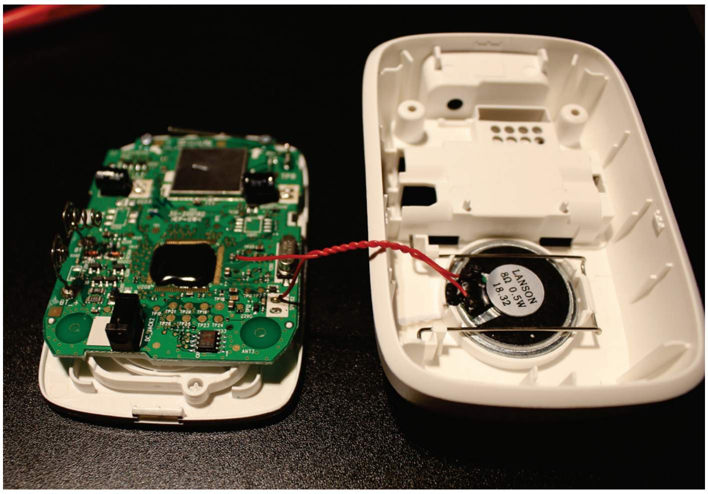

***Figure 2**. The inside of the baby monitor.*

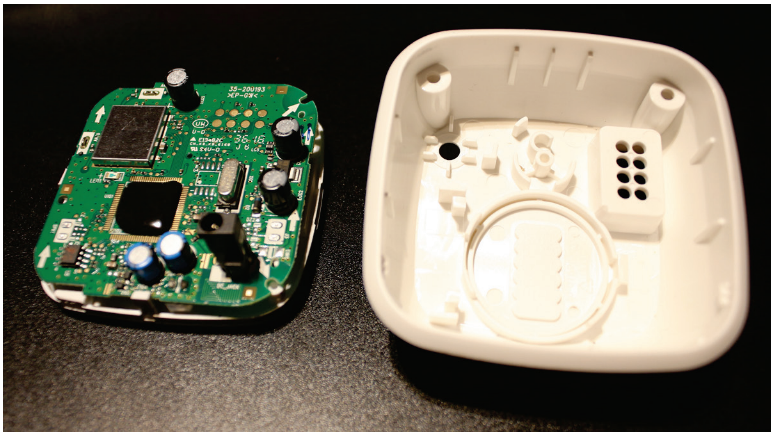

***Figure 3**. The inside of the baby monitor.*

Miniland baby by Miniland S.A. Spain, manufactured in China

Baby unit
On Off switch,
LED indicator
Night light
Adapter: 6 V DC / 300 mA

Parent unit
On Off switch,
Rise/lower volume
Battery time 5...8 hours
Adapter: 6 V DC / 300 mA
2x AAA 1.2 V 800mAh
Ni-MH batteries

directive R&TTE1995/5/CE,
2005/32/CE

frequency 2.4 GHz

Range 300 m open space

Transmission power
Average 10 mW
Maximum 250 mW

***Figure 1**. The outside of the baby monitor.*

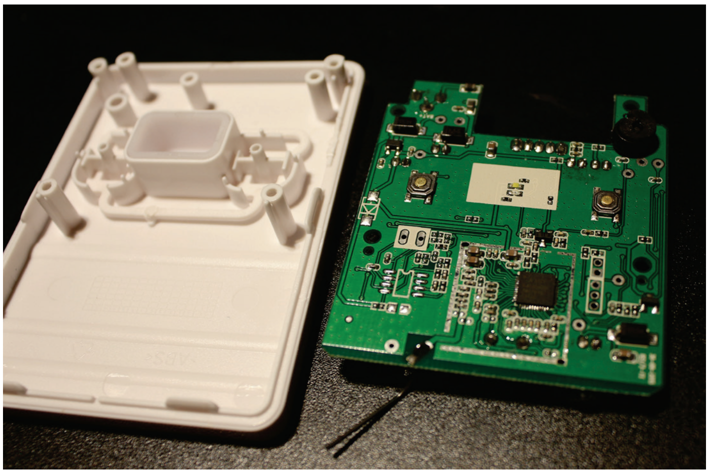

***Figure 2**. The inside of the baby monitor.*

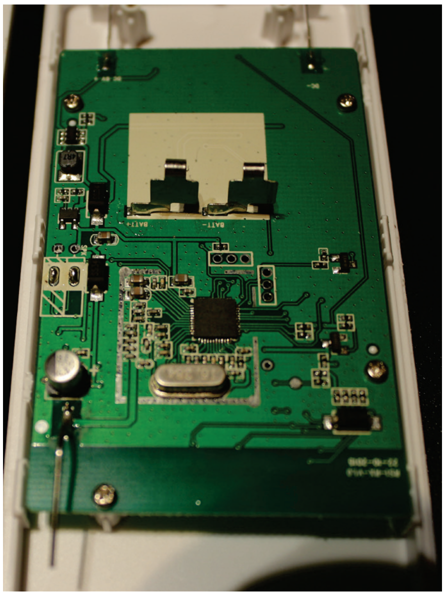

***Figure 3**. The inside of the baby monitor.*

Philips AVENT SCD 71x/72x/73x

Adapter: 6 V DC / 0.5 A

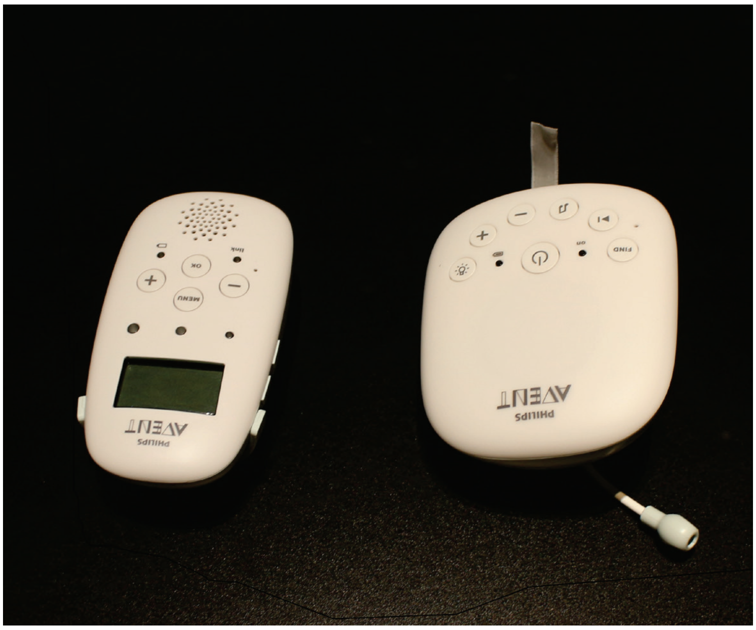

Figure 1. *The outside of the baby monitor.*

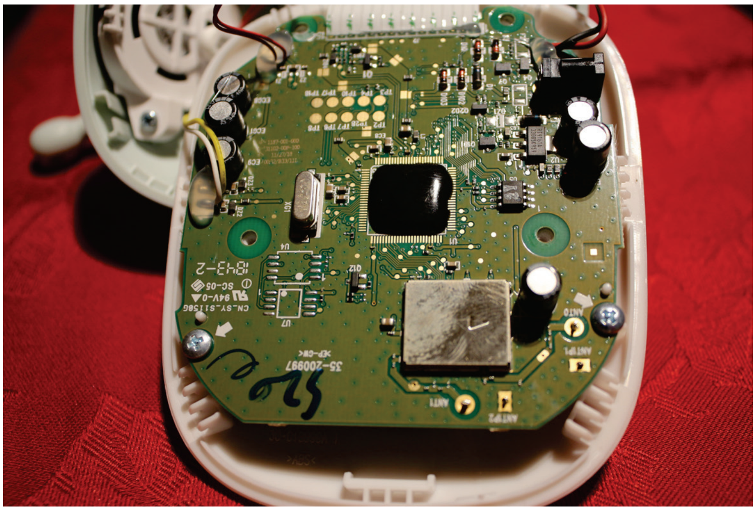

Figure 2. *The inside of the baby monitor.*

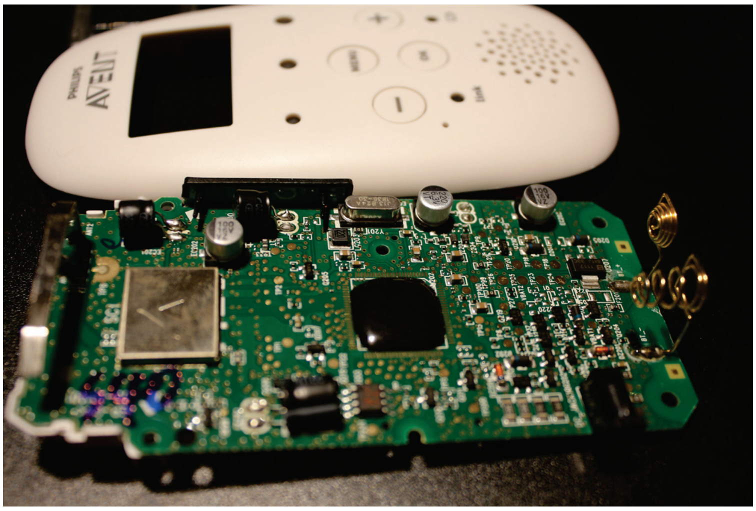

Figure 3. *The inside of the baby monitor.*

Portable Baby Shooter by ZAZU, The Neatherlands

Power : 3 AAA batteries

Noises it makes for 20 min before shut-off (6):
Shhhhhhh
Wite noise
Heartbeat
Ocean waves
Calming music
lullabies

Figure 1. *The outside of the baby monitor.*

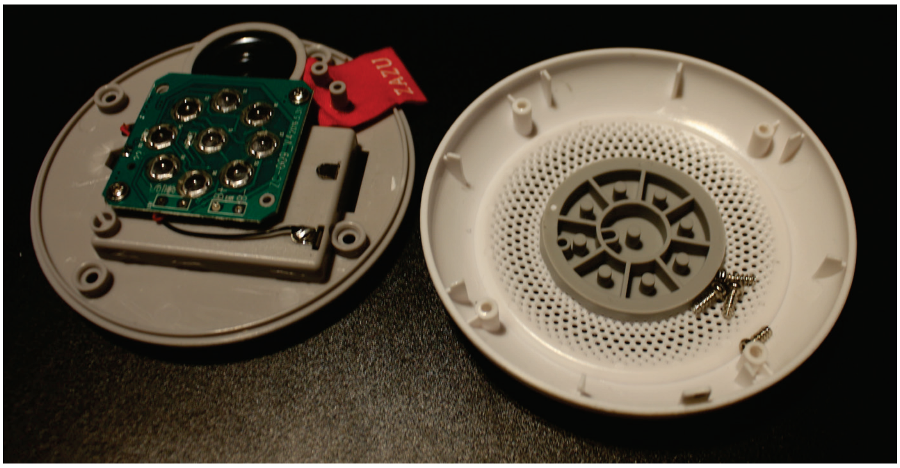

Figure 2. *The inside of the baby monitor.*