Form 24

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

National University «Zaporizhzhya Polytechnic»

Faculty of Radio Electronics and Telecommunications

Information Technologies of Electronic Means

Explanatory note

to the diploma project (work)

Master

"Investigation of baseline wander removal approaches in the electrocardiogram recordings"

Completed by 6th year student of RT 519M group

Speciality 172 "Telecommunications and radio engineering"

Educational program "Intelligent technologies of microsystem radio electrical engineering"

Tverdokhlib V.

Supervisor Shilo G.

Reviewer Zelenova I.

Form 25

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

National University «Zaporizhzhya Polytechnic»

Institute, Faculty: Institute of Informatics and Radio Engineering; Faculty of Radio Electronics and Telecommunications
Department: Information Technologies of Electronic Means
Degree of higher education: master
Specialty: 172 "Telecommunications and radio engineering"
Educational program (specialization): «Intelligent technologies of microsystem radio electrical engineering»

I APPROVE
Head of the Department Shilo G.
Ph.D. Associate Professor of ITEM department
« _______ » _______________ 20 ___

T A S K
FOR DIPLOMA PROJECT (WORK) FOR A STUDENT

Tverdokhlib Vladyslava

1. Subject of a project (work) "Investigation of baseline wander removal approaches in the electrocardiogram recordings"

Supervisor of a project (work) Shilo G. Ph.D. Associate Professor of ITEM department approved by the order of the institution of higher education from 15.10.2020 № 450
2. Deadline for student submission of a project (work) ______________________
3. Initial data to the project (work): types of noise in electrocardiogram signals, methods and algorithms for their elimination, electrocardiogram signal recording distorted by baseline wander.
4. Contents of the settlement and explanatory note (list of issues to be developed)
   1. The concept of biomedical technologies;
   2. Electrocardiograph signal, properties;
   3. Removal of mains noise;
   4. Economic justification of work;
   5. Occupational health and safety in emergencies.
5. List of graphic material (with the exact indication of obligatory drawings): presentation 20 slides

6. Consultants of the sections is CTS (work)

Chapter	Surname, initials and position of consultant	Signature, date	
		Task issued	Task accepted
1-5	Shilo G.		
6	Levchenko N.		
7	Yakimcev Y.		
8	Pospeeva I.		

7. Date of issuance of the task 15.10.2020

CALENDAR PLAN

№	Name of stages of diploma project (work)	Term of execution stages of project (works)	Note
1	Analysis of input data	2 weeks	
2	Review of the field of development and solution of tasks	2 weeks	
3	Development of filters and noise removal	4 weeks	
4	Testing the operation of filters	3 weeks	
5	Calculation of economic efficiency	1 week	
6	Occupational health and safety in emergencies	1 week	
7	Analysis of initial data	2 weeks	

Student ____________ Tverdokhlib V.
(signature)

Supervisor of a project ____________ Shilo G.
(signature)

Форма № 24

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

Національний університет «Запорізька політехніка»

Факультет радіоелектроніки та телекомунікацій

(повне найменування інституту, факультету)

Інформаційні технології електронних засобів

(повне найменування кафедри)

Пояснювальна записка

до дипломного проєкту (роботи)

магістр

(ступінь вищої освіти)

на тему Дослідження засобів видалення дрейфу базової лінії в сигналах електрокардіограм

Виконав: студент(ка) VI курсу, групи РТ 519 М

Спеціальності 172 Телекомунікація та радіотехніка

(код і найменування спеціальності)

Освітня програма (спеціалізація)

Інтелектуальні технології мікросистемної радіоелектронної техніки

Твердохліб В.С.

(прізвище та ініціали)

Керівник Шило Г. М.

(прізвище та ініціали)

Рецензент Зеленьова І. Я.

(прізвище та ініціали)

Форма № 25

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
Національний університет «Запорізька політехніка»
(повне найменування закладу вищої освіти)

Інститут інформатики та радіотехніки,
Інститут, факультет факультет радіотехніки та телекомунікацій
Кафедра Інформаційні технології електронних засобів
Ступінь вищої освіти магістр
Спеціальність 172 „Телекомунікації та радіотехніка"
(код і найменування)
Освітня програма (спеціалізація) Інформаційні технології мікросистемної
(назва освітньої програми (спеціалізації)
радіоелектронної техніки

ЗАТВЕРДЖУЮ
Завідувач кафедри Шило Г. М.
д. т. н. доцент кафедри ІТЕЗ
«15» 12 2020 року

З А В Д А Н Н Я
НА ДИПЛОМНИЙ ПРОЄКТ (РОБОТУ) СТУДЕНТА(КИ)

Твердохліб Владислава Сергіївна
(прізвище, ім'я, по батькові)

1. Тема проєкту (роботи) Дослідження засобів видалення дрейфу базової лінії в сигналах електрокардіограм

керівник проєкту (роботи) Шило Галина Миколаївна, д.т.н, доцент кафедри ІТЕЗ,
(прізвище, ім'я, по батькові, науковий ступінь, вчене звання)
затверджені наказом закладу вищої освіти від « 15 » жовтня 20 20 року № 450

2. Строк подання студентом проєкту (роботи) 24.12.2020
3. Вихідні дані до проєкту (роботи) типи перешкод в сигналах електрокардіограм, методи та алгоритми їх усунення, сигнал електрокардіограми зпотворений дрейфом базової лінії

4. Зміст розрахунково-пояснювальної записки (перелік питань, які потрібно розробити) 1. Обробка біомедичних сигналів
2. Поняття електрокардіографії
3. Аналіз та систематизація перешкод в електрокардіограмах
4. Видалення дрейфу базової лінії
5. Економічне обгрунтування роботи
6. Охорона праці та безпека в надзвичайних ситуаціях
5. Перелік графічного матеріалу (з точним зазначенням обов'язкових креслень)
Презентація (22 слайда)

Консультанти розділів проєкту (роботи)

Розділ	Прізвище, ініціали та посада консультанта	Підпис, дата	
		завдання видав	прийняв виконане завдання
1-5	Шишо Г. М. д.т.н. доцент каф. ІТЕЗ	[signature]	[signature]
6	Левченко Н. М.		
7	Якимцов Ю. В.	[signature]	[signature]
8	Поспеєва І. Е		

Дата видачі завдання « 15 » жовтня 2020 року.

КАЛЕНДАРНИЙ ПЛАН

№ з/п	Назва етапів дипломного проєкту (роботи)	Срок виконання етапів проєкту (роботи)	Примітка
1	Аналіз вихідних даних	3 тижні	
2	Огляд області розробки і постанова завдань	2 тижні	
3	Розробка фільтрів видалення дрейфу	4 тижні	
4	Тестування роботи фільтрів базової лінії	3 тижні	
5	Розрахунок економічної ефективності	1 тиждень	
6	Охорона праці та безпека у надзвичайних ситуаціях	1 тиждень	
7	Аналіз вихідних даних	2 тижні	

Студент(ка) [signature] Твердохліб В.
(підпис) (прізвище та ініціали)

Керівник проєкту (роботи) [signature] Шишо Г. М.
(підпис) (прізвище та ініціали)

Форма № 24

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
Національний університет «Запорізька політехніка»

Факультет радіоелектроніки та телекомунікацій
(повне найменування інституту, факультету)

Інформаційні технології електронних засобів
(повне найменування кафедри)

Пояснювальна записка

до дипломного проєкту (роботи)

Магістр
(ступінь вищої освіти)

на тему Дослідження засобів видалення дрейфу базової лінії в сигналах електрокардіограм

Виконав: студент(ка) VI курсу, групи РТ 519 М

Спеціальності 172 Телекомунікація та радіотехніка
(код і найменування спеціальності)

Освітня програма (спеціалізація)
Інтелектуальні технології мікросистемної радіоелектронної техніки

Твердохліб В.С.
(прізвище та ініціали)

Керівник Шило Г. М.
(прізвище та ініціали)

Рецензент Зленьова І. Я.
(прізвище та ініціали)

Форма № 25

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
Національний університет «Запорізька політехніка»
(повне найменування закладу вищої освіти)

Інститут, факультет Інститут інформатики та радіотехніки, факультет радіотехніки та телекомунікацій
Кафедра Інформаційні технології електронних засобів
Ступінь вищої освіти магістр
Спеціальність 172 „Телекомунікації та радіотехніка"
(код і найменування)
Освітня програма (спеціалізація) Інформаційні технології мікросистемної радіоелектронної техніки
(назва освітньої програми (спеціалізації))

ЗАТВЕРДЖУЮ
Завідувач кафедри Шило Г. М.
к. т. н. доцент кафедри ІТЕЗ
«______» ______________ 20___ року

З А В Д А Н Н Я
НА ДИПЛОМНИЙ ПРОЄКТ (РОБОТУ) СТУДЕНТА(КИ)

Твердохліб Владислава Сергіївна
(прізвище, ім'я, по батькові)

1. Тема проєкту (роботи) Дослідження засобів видалення дрейфу базової лінії в сигналах електрокардіограм

керівник проєкту (роботи) Шило Галина Миколаївна, к.н.т. доцент кафедри ІТЕЗ,
(прізвище, ім'я, по батькові, науковий ступінь, вчене звання)
затверджені наказом закладу вищої освіти від «15» жовтня 2020 року № 450
2. Строк подання студентом проєкту (роботи) __________
3. Вихідні дані до проєкту (роботи) типи перешкод в сигналах електрокардіограм, методи та алгоритми їх усунення, розробка фільтрів для усунення дрейфу базової лінії в середовищі програми Matlab

4. Зміст розрахунково-пояснювальної записки (перелік питань, які потрібно розробити) 1. Обробка біомедичних сигналів
2. Поняття електрокардіографії
3 Аналіз та систематизація перешкод в електрокардіограмах
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5. Економічне обгрунтування роботи
6. Охорона праці та безпека в надзвичайних ситуаціях
5. Перелік графічного матеріалу (з точним зазначенням обов'язкових креслень)
Презентація (21 слайд)

6. Консультанти розділів проєкту (роботи)

Розділ	Прізвище, ініціали та посада консультанта	Підпис, дата	
		завдання видав	прийняв виконане завдання
1	Шило Г.М. к.т.н. доцент каф ІТЕЗ		
2	Левченко Н. М.		
3	Якимцов Ю. В.		

7. Дата видачі завдання «15» жовтня 2020 року.

КАЛЕНДАРНИЙ ПЛАН

№ з/п	Назва етапів дипломного проєкту (роботи)	Строк виконання етапів проєкту (роботи)	Примітка
1	Аналіз вихідних даних	3 тижні	
2	Огляд області розробки і постанова завдань	2 тижні	
3	Розробка фільтрів видалення дрейфу	4 тижні	
4	Тестування роботи фільтрів базової лінії	3 тижні	
5	Розрахунок економічної ефективності	1 тиждень	
6	Охорона праці та безпека у надзвичайних ситуаціях	1 тиждень	
7	Аналіз вихідних даних	2 тижні	

Студент(ка) ____________ Твердохліб В.
(підпис) (прізвище та ініціали)

Керівник проєкту (роботи) ____________ Шило Г.М.
(підпис) (прізвище та ініціали)

PROJECT OVERVIEW

Project: 97 p., 18 fig., 15 tab., 22 ref.

The main objective of this project is to design filters which can detect baseline wander noise from ECG signal and get rid of it. In this work we will implement and compare several methods which are widely used for the elimination of baseline wander.

Introduction overviews existing problems with cardiovascular diseases nowadays and indicates ways to improve the quality of prevention and treatment of these diseases by showing the importance of finding new methods of struggling against interferences in electrocardiogram.

Chapter 1 puts biomedical signal processing in context and gives a brief description of bioelectricity and its manifestation on the body surface as signals. General aspects on signal acquisition and performance evaluation are briefly considered.

Chapter 2 contains a background to the electrophysiology of the heart and describes the main characteristics of the ECG signal in terms of morphology and rhythm.

Chapter 3 contains an overview of the main types of interference arising during registration. The reasons for their occurrence are also considered. Then it describes a suite of methods, essential to any system which performs ECG signal analysis, developed for the purpose of noise reduction, heartbeat detection and delineation, and data compression.

Chapter 4 Overview such methods of filtering as Linear, Time-Invariant Filtering and Forward-backward IIR filtering.

Chapter 5 Provides an economic justification for this project.

Chapter 6 contains information on occupational safety and health in emergency situation.

ELECTROCARDIOGRAM, SIGNAL, FILTERING, BASELINE WANDER, INTERFERENCE, PROCESS, FREQUENCY, NOISE

INDEX

ABSTRACT

1. Description

Cardiovascular diseases are the leading cause of death all over the world. As a result, there is a growing demand for diagnostic and therapeutic tools necessary for the study and treatment of patients with these abnormalities. The electrocardiogram (ECG) is the simplest and most common non-invasive technique in the diagnosis of heart diseases. The ECG is strongly affected by some types of noise, like baseline wander. Baseline wandering is a typical problem in ECG records, that generally produces artefactual data while measuring ECG parameters. Baseline wander is a low frequency artifact in the ECG that arises from breathing, electrically charged electrodes, or subject movement, and can hinder the detection of changes in the ST segment (which is essential for diagnosing some cardiac pathologies) because of the varying electrical isoline. Hereford, even minor fluctuations in baseline can lead to the decision if a patient is classified as ST-Elevation Myocardial Infarction (STEMI) or non-STEMI and thus influence the therapeutic approach dramatically. Baseline interferences are especially relevant in ECG records obtained during exercise testing. The frequency components of the baseline wander are usually below 0.5 Hz but, in case of stress tests, this limit can be higher. Thus, these components can be in the same range than the low frequency ECG components, like those of the ST segment. Then, removal of the baseline can adversely alter the ECG clinical information.

Several methods have been used to eliminate the baseline wander. The most classical one is ensemble averaging. This approach is adequate when the ECG signal remains constant in each beat, but this is not the situation in many actual ECG records. Other method is polynomial interpolation. Linear interpolation introduces significant distortions. A third order approximation called cubic spline achieves better results. Interpolation makes use of a previous knowledge of the ECG isoelectric levels estimated from the PR intervals, also called knots. This is a

nonlinear approach whose performance depends on the knots determination accuracy, and it is degraded as the knots become more separated (low heart rate). Another method that overcomes this problem is digital highpass linear phase filtering. This method can be implemented in real time, but has two major problems: first, the filter requires either to be an FIR filter with a long impulse response and a large number of coefficients or an IIR filter with forward-backward filtering (thus precluding on-line implementation); second, given that ECG and baseline wander spectra usually overlap, it is not possible to remove the baseline wander with a linear filter without distorting the ECG components. The time-varying filtering technique, that selects different cut-off frequencies of the linear filter as a function of the heart rate or the baseline level, improves the time invariant FIR filter performance, but can yet distort the ST components and has high computational requirements. Adaptive filtering has been recently proposed to cancel the baseline drift. This filter is an adaptive transversal filter with one weight, where the reference input is a constant with a value of 1 and the primary input is the ECG signal. This filter, using the LMS algorithm in the adaptation process, is equivalent to a linear highpass filter, that takes the advantage of the adaptive implementation, but still modifies the ST components.

2. Methodology

In this work we will implement several methods which are used in the literature for the elimination of baseline wander in the ECG, comparing their performance in terms of the attained mean squared error (MSE): starting from a simple high pass fitter, and then using cascade adaptive filters to preserve the overlapped deterministic low frequency components of the ECG, such as ST segment components. This cascade adaptive filter works in two stages. The first stage is an adaptive notch filter at zero frequency. The second stage is an adaptive impulse correlated filter that estimates the ECG signal correlated with the QRS occurrence. In both stages the LMS algorithm is used with different adaptation factors µ1 and µ2. We will analyse the frequency response of the filter as a function of the µ1 and µ2 parameters, selecting those more appropriated for baseline removal. Finally, the performance of the filter is studied on an actual ECG affected by baseline drift and we will compare the results after using different types of filters with each other and with clean ECG signals (like signal 118m from the MIT-BIH database)

3. Tasks

The main tasks performed in the thesis is here been following:

- download the clean ECG signals and the baseline wander noise from Physionet;
- design a high pass filter with optimal parameters;
- create cascade adaptive filter preserving the overlapped deterministic low frequency components of the ECG;
- compare results of implemented algorithms.

4. Materials to be used

The following in materials have been used in this project:

- software: Windows 10 Enterprise x64 (1703 build 15063), MATLAB R2019b;
- hardware: Apple MacBook Pro 13 A1502.

5. Discussion

Cardiovascular Diseases (CVD) rank first among the causes mortality of the population of our planet according to the World health organization (WHO), accounting for about a third of all cases of death. In Europe, almost a million people die from these diseases every year (at least 50% of all deaths), of which about 100 thousand are people at working age. In addition, experts (WHO) forecast a further increase in cardiovascular morbidity and mortality, as in developed and developing countries, due to aging populations and lifestyle features. According to preliminary data, in 2030 myocardial infraction and stroke will remain the main individual causes of death [1].

In this regard, there is a need for accurate and timely diagnosis of diseases of the cardiovascular system in the early stages development, which is one of the strategic directions of the health care industry. The basis of such a diagnosis is electrocardiography (ECG). This method is a non-invasive examination of the bioelectrical activity of the heart. Currently this method of diagnosis is indispensable for rhythm and conduction disorders, hypertrophy of the ventricles and atria, coronary heart disease, including painless form, myocardial infarction and other dangerous pathologies.

However, in connection with the peculiarities of physiological origin and registration of signals, there is a serious and unsolved problem of their automatic analysis. ECG signals are unsteadily structured signals with cyclically repeating informative sections. Specifically, according to these signs, the state of the cardiovascular system is assessed in electrocardiography. Morphology and parameters are diverse, variable, and unpredictable.

In addition, it should be borne in mind that, while electrocardiography is recorded, it is inevitable in record also numerous interferences and noises in the signal. There are various kinds and origins that influence signal, leading to morphological changes in the electrocardiogram. In some cases, such changes do not have diagnostic importance, but sometimes they can be mistakenly considered as signs of myocardial damage, leading to inaccurate or erroneous automatic conclusions.

As a result of this problem, in cardiac diagnostics is development of various methods and algorithms for noise suppression. Have been developed each method for such problems has advantages and disadvantages, therefore, why in this project we analyze different methods to struggle against interferences. The effectiveness of noise suppression will be determined by the degree of suppression of interference and the degree of preservation of diagnostic information.

Improving the efficiency of noise suppression makes it possible to increase the reliability of automatic conclusions, and ultimately contributes to improving the quality of prevention and treatment.

The aim of this work is to develop and test methods for suppressing interference. The main objectives of the thesis are the following:

1) research about general information about electrocardiography;

2) review types of interferences which are arising in electrocardiograms;

3) overview methods and algorithms for interference suppression in electrocardiograms;

4) develop methods which overcome baseline wander interference;

5) test the designed filters;

6) compare filters by using different methods for suppressing interference.

1 BIOMEDICAL SIGNAL PROCESSING

1.1 Introduction

Chapter 1 puts biomedical signal processing in context and gives a brief description of bioelectricity and its manifestation on the body surface as signals. General aspects on signal acquisition and performance evaluation are briefly considered. The chapter consist of:

1.1 – introduction.

1.2 – show the main objectives of biomedical signal processing.

1.3 – represents the purpose of major clinical contexts for biomedical signal processing.

1.4 – fundamentals in bioelectrical signals.

1.5 – discussion – show short overview of chapter 1.

1.2 Objectives

A fundamental objective of biomedical signal processing is to reduce the subjectivity of manual measurements [2]. The introduction of computer-based methods for the purpose of objectively quantifying different signal characteristics is the result of a desire to improve measurement accuracy as well as reproducibility. In addition to reducing measurement subjectivity, biomedical signal processing is used for developing methods that extract features to help characterize and understand the information contained in a signal. Such feature extraction methods can be designed to mimic manual measurements, but are equally often designed to extract information which is not readily available from the signal through visual assessment. For example, small variations in heart rate that cannot be perceived by the human eye have been found to contain very valuable clinical information when quantified in detail using a suitable signal processing technique. Although it is certainly desirable to extract features that have an intuitive meaning to the physician, it is not necessarily those features which yield the best performance in clinical terms [4].

In many situations, the recorded signal is corrupted by different types of noise and interference, sometimes originating from another physiological process of the body. For example, situations may arise when ocular activity interferes with the desired brain signal, when electrodes are poorly attached to the body surface, or when an external source, such as the sinusoidal 50/60 Hz powerline, interferes with the signal. Hence, noise reduction represents a crucial objective of biomedical signal processing so as to mitigate the technical deficiencies of a recording, as well as to separate the desired physiological process from interfering processes. In fact, the desired signal is in certain situations so dramatically masked by noise that its very presence can only be revealed once appropriate signal processing has been applied. This is particularly evident for certain types of transient, very low-amplitude activity, such as evoked potentials, which are part of brain signals, and late potentials, which are part of heart signals.

Certain diagnostic procedures require that a signal be recorded on a long timescale, sometimes lasting for several days. Such recordings are, for example, routinely achieved for the purpose of analyzing abnormal sleep patterns or to identify intermittently occurring disturbances in the heart rhythm. The resulting recording, which often involves many channels, amounts to huge data sizes, which quickly fill up hard disk storage space once a number of patients have been examined. Transmission of biomedical signals across public telephone powerlines is another increasingly important application in which large amounts of data are involved. For both of these situations, data compression of the digitized signal is essential and, consequently, another objective of biomedical signal processing. General-purpose methods of data compression, such as those used for sending documents over the Internet, do not perform particularly well, since the inherent characteristics of the biomedical signal are not at all exploited. Better performance can be obtained by applying tailored algorithms for data compression of biomedical signals[3]. Data compression can also be understood in a wider sense as the process in which clinical information from a long-term recording is condensed into a smaller data set that is more manageable for the person analyzing the data. In this latter sense, it is highly desirable to develop signal processing algorithms which are able to determine and delimit clinically significant episodes.

Mathematical signal modeling and simulation constitute an other important objectives in biomedical signal processing which can help to attain a better understanding of physiological processes. With suitably defined model equations it is possible to simulate signals which resemble those recorded on the cellular level or on the body surface, thereby offering insight into the relationship between the model parameters and the characteristics of the observed signal. Examples of bioelectrical models include models of the head and brain for localizing sources of neural activity and models of the thorax and the heart for simulating different cardiac rhythms. Signal modeling is also central to the branch of signal processing called "model-based signal processing," where algorithm development is based on the optimization of an appropriately selected performance criterion [7]. In employing the model-based approach, the suggested signal model is fitted to the observed signal by selecting those values of the model parameters which optimize the performance criterion. While model-based biomedical signal processing represents a systematic approach to the design of algorithms, it does not always lead to superior performance; heuristic approaches may actually perform just as well and sometimes even better. It is a well-known fact that many commercial, medical devices rely on the implementation of “ad hoc” techniques in order to achieve satisfactory performance [2].

The complexity of a signal model depends on the problem to be solved. In most signal processing contexts, it is fortunately not necessary to develop a multilevel model which accounts for cellular mechanisms, current propagation in tissue, and other biological properties. Rather, it is often sufficient to develop a "phenomenological" model which only accounts for phenomena which are relevant to the specific problem at hand [4].

1.3 Clinical context

The purpose of this section is to point out the three major clinical contexts in which algorithms for biomedical signal processing are designed [4], namely, the contexts of

- diagnosis;
- therapy;
- monitoring.

In the diagnostic context, medical conditions are identified from the examination of signal information, reflecting the function of an organ such as the brain or the heart, in combination with other symptoms and clinical signs. A signal is often acquired by a noninvasive procedure, which makes the examination less taxing on the patient. Most of these procedures are also associated with inexpensive technology for acquisition and analysis, thus increasing the likelihood that the technology can be disseminated to countries with less developed economies. A diagnostic decision rarely requires immediate availability of the results from signal analysis, but it is usually acceptable to wait for some time(from a few minutes to some hours or even days) for the analysis to be completed. Hence, signal analysis can be done off-line on a personal computer, thus relying on standardized hardware and operating system, possibly supplemented with a digital signal processor (DSP) board for accelerating certain bottleneck computations. Algorithms for biomedical signal processing do not define the entire diagnostic computer system, but their scope ranges from performing a simple filtering operation to forming a more substantial part of the clinical decision-making.

Therapy generally signifies the treatment of disease and often involves drug therapy or surgery. With regard to biomedical signal processing, therapy may imply a narrower outlook in the sense that an algorithm is used to directly modify the behavior of a certain physiological process, for example, as the algorithms of a pacemaker do with respect to cardiac activity. In a therapeutic context, an algorithm is commonly designed for implementation in an implantable device like a heart defibrillator, and, therefore, it must, unlike an algorithm operating in a diagnostic context, strictly comply with the demands of on-line, real-time analysis. Such demands pose some serious constraints on algorithmic complexity as well as on the maximal acceptable time delay before a suitable action needs to be taken. Low power consumption is another critical factor to be considered in connection with devices that are implanted through a surgical procedure; for example, the battery of an implantable device is expected to last up to ten years. Hence, algorithms which involve computationally demanding signal processing techniques are less suitable for use in a therapeutic context.

Biomedical signal processing algorithms form an important part of real time systems for monitoring of patients who suffer from a life-threatening condition. Such systems are usually designed to detect changes in cardiac or neurological function and to predict the outcome of a patient admitted to the intensive care unit (ICU). Since such changes may be reversible with early intervention, irreversible damage can sometimes be prevented. Similar to therapeutic contexts, the signal is processed during monitoring in an essentially sequential fashion such that past samples constitute the main basis for a decision, while just a few seconds of the future samples may also be considered, which usually stands in sharp contrast to signal processing for diagnostic purposes, where the signal is acquired in its entirety prior to analysis. Thus, a noncausal approach to signal analysis can only be adopted in the diagnostic context, which mimics that of a human reader who interprets a signal by making use of both past and future properties. Constraints need to be imposed on the algorithmic design in terms of maximal delay time, because the occurrence of a life-threatening event must be notified to the ICU staff within a few seconds. Other important issues to be considered are the implications of a clinical event that is missed by the algorithm or the implications of a nonevent that is falsely detected causing the staff to be notified.

1.4 Basics of Bioelectrical Signals

Bioelectrical signals are related to ionic processes which arise as a result of electrochemical activity of a special group of cells having the property of excitability. The mechanisms which govern the activity of such cells are similar, regardless of whether the cells are part of the brain, the heart, or the muscles. In particular, the electrical force of attraction has central importance for the processing and transmission of information in the nervous system, as well as for sustaining the mechanical work done by the heart and the muscles.

The ability of excitable cell membranes to generate action potentials causes a current to flow in the tissue that surrounds the cells. With the tissue being a conducting medium, commonly referred to as a volume conductor, the collective electrical activity of many cells can be measured noninvasively on the body surface. The recording of a bioelectrical signal in clinical practice is done by attaching at least two electrodes to the body surface. The "exploring" electrode, placed close to the electrical source, and the "indifferent" electrode, placed elsewhere on the body surface. Multiple electrode configurations are commonly used in clinical practice to obtain a spatial description of the bioelectrical phenomenon. Since the activity of excitable cells is viewed from a distance by the electrodes, with different tissues in between, such as blood, skeletal muscles, fat, and bone, it is impossible to noninvasively determine detailed information about cellular properties and propagation patterns. Nonetheless, significant empirical knowledge has been acquired over the years from analyzing the patterns of signals recorded on the body surface, which have been found crucial for clinical decision-making.

The problem of characterizing the electrical source by noninvasive measurements has, in spite of the above-mentioned limitations, been the subject of considerable research due to the far-reaching clinical implications of its potential solution. In order to arrive at a meaningful solution, it is necessary to introduce a mathematical model in which the collective electrical cellular activity is treated as a volume source, i.e., it is defined by a fixed dipole, a multiple dipole, or some other source model. Furthermore, by introducing a model for the volume conductor which accounts for essential properties of the human body, such as geometry and resistivity, the electrical field measured on the body surface can be modeled. The important inverse problem consists of determining the electrical source from measurements on the body surface under the assumption that the geometry and electrical properties of the volume conductor are known.

The properties of signals which take place call for widely different processing techniques; an individual waveform can in some signals be directly linked to a specific clinical diagnosis, while in other signals many waveforms must be analyzed before a meaningful interpretation can be made. This project deals with the processing of electrical signals that describe the activity of the heart.

The electrocardiogram (ECG) reflects the electrical activity of the heart and is obtained by placing electrodes on the chest, arms, and legs, see Figure 1.1. With every heartbeat, an impulse travels through the heart, controlling its rhythm and rate, and causing the heart muscle to contract and pump blood. The ECG represents a standard clinical procedure for the investigation of heart diseases such as myocardial infarction.

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Figure 1.1 – Example of bioelectrical signal - an electrocardiogram (ECG), recorded from the body surface [5].

1.5 Discussion

1.5.1 The main objectives of biomedical signal processing are the following.

1.5.1.1 Reducing the subjectivity of manual measurements by applying computer-based methods for the purpose of objectively quantifying different signal characteristics. As a result - improving measurement accuracy and reproducibility.

noise reduction - mitigating technical deficiencies of a recording and separating the desired physiological process from interfering processes. Clean signals are always masked by noise and interference and they can only be revealed once appropriate signal processing has been applied.

1.5.1.2 Data compression. Struggles with easily filled disk storage by, for example, long timescale signal recordings, which in consequence would be more complicated for transmission. Also, in clinical information from a long-term recording is condensed into a smaller data set which is more manageable for the person who analyzing the data. Better performance can be obtained by applying tailored algorithms for data compression of biomedical signals.

1.5.1.3 Mathematical signal modeling and simulation could help to attain a better understanding of physiological processes. With suitably defined model equations it is possible to simulate signals which resemble those recorded on the cellular level or on the body surface, thereby offering insight into the relationship between the model parameters and the characteristics of the observed signal.

1.5.2 Clinical contexts for biomedical signal processing are following.

1.5.2.1 Diagnosis - examination of signal information, reflecting the function of an organ such as the brain or the heart, in combination with other symptoms and clinical signs.

1.5.2.2 Therapy - treatment of disease and often involves drug therapy or surgery. With regard to biomedical signal processing, therapy may imply a narrower outlook in the sense that an algorithm is used to directly modify the behavior of a certain physiological process.

1.5.2.3 Monitoring - real time systems for observing patients who suffer from a life-threatening condition, which may be reversible with early intervention and irreversible damage could be prevented.

1.5.3 The electrocardiogram (ECG) reflects the electrical activity of the heart and is obtained by placing electrodes on the chest, arms, and legs. With every heartbeat, an impulse travels through the heart, controlling its rhythm and rate, and causing the heart muscle to contract and pump blood. The ECG represents a standard clinical procedure for the investigation of heart diseases, such as myocardial infarction.

2 CONCEPTS OF ELECTROCARDIOGRAPHY

2.1 Introduction

Chapter 2 contains a background to the electrophysiology of the heart and describes the main characteristics of the ECG signal in terms of morphology and rhythm. The chapter consist of:

2.1 – introduction.

2.2 – provides information about ECG: how it is generated, its main components and parameters. In pathology, these parameters can vary significantly, which makes it possible to use electrocardiography in the diagnosis of many heart diseases.

2.3 – demonstrate the role of signal processing in analyzing ECG recordings.

2.4 – shows introduction in types of filtering ECG signals – linear and nonlinear.

2.5 – discussion – show short overview of chapter.

2.2 Structure, characteristics and parameters of electrocardiograms

Electrocardiography - electrophysiological study of heart activity based on registration and analysis of the electrical activity of the myocardium, which leads to the pervasive heartbeat. The curve obtained as a result of the process of electrocardiography is called an electrocardiogram.

This method of studying the bioelectrical activity of the heart is today indispensable in the diagnosis of rhythm and conduction disorders, hypertrophy of the ventricles and atria, coronary heart disease, myocardial infarction and other heart diseases [8].

The main advantages of electrocardiography are [2] :

- high information content and reliability;
- painlessness and safety;

- efficiency of research;
- lack of contraindications.

An electrocardiogram is a signal which is displaying the contractile activity of the heart and can be easily recorded using surface electrodes placed on the limbs or chest. The electrocardiogram, isprobably, the most widely known, recognized, and used biomedical signal.

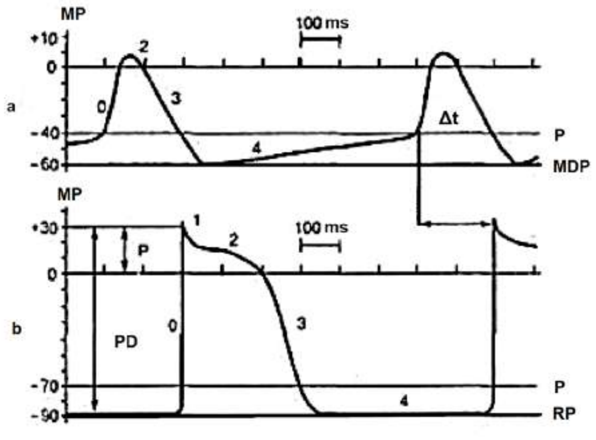
2.2.1 Electrical phenomena in the heart

The occurrence of electrical phenomena in the heart is based on a change in the concentration of potassium (K^+), sodium (Na^+) and calcium (Ca^{2+}) ions, as well as chlorine (Cl), inside and outside myocardial cells under the influence of an electrical impulse. In moment of rest, the outer surface of the membrane is positively charged, and the inner is negatively charged due to the uneven distribution of charged ions. This potential difference between the intracellular and extracellular environment is called the resting potential (RP) and is approximately 80 mV in the myocardium of the atria and ventricles, 90 mV in the His-Purkinje system(see Figure 2.2), and 60 mV in the sinus (SU) and atrioventricular nodes (AVN) [4].

The concentration of Na^+ ions is 20 times higher in the extracellular medium than inside the cell, Cl^- ions is 13 times higher and Ca^{2+} ions is 25 times higher. On the contrary, the concentration of K^+ ions inside the cell is 30 times higher than in the extracellular fluid. Such high ion concentration gradients on both sides of the membrane are maintained due to the functioning of ion pumps in it, with the help of which Na^+, Ca^{2+} and Cl^- ions are removed from the cell, and K^+ ions enter the cell. If an electric stimulus of sufficient strength is applied to the cell membrane to change the resting potential value to the level of the threshold potential, rapid depolarization occurs - a sudden change in charge inside the cell to positive (up to +20 or +30 mV). Depolarization, or zero phase, of the action potential (PD) is due to the rapid entry of sodium ions into the cell.

After depolarization (phase 0) a much slower process of repolarization begins - the restoration of the initial resting potential. In the cells of the working myocardium and His-Purkinje system, the first phase of repolarization (phase 1) occurs rather quickly and is due to the release of K^+. It is believed that in phase 1, the current Cl^- takes part inward. In the plateau phase (phase 2), against the background of the current K^+, Ca^{2+} (and to a lesser extent Na^+) enters through the so-called — slow channels. As a result, the speed of depolarizing and repolarizing currents is balanced for a time and an action potential plateau appears. At the end of the plateau, the slow channels begin to close, and the conductivity for K^+, on the contrary, increases sharply — the polarization accelerates (phase 3) and a return to the initial resting potential level occurs. After this, diastole begins (phase 4).

In the cells of the CA-site and the AB-compound, fast sodium channels are absent. Therefore, the depolarization of the membranes of these cells is almost completely determined by the slow incoming current of Ca^{2+}. Since the intensity of this current is small, and its duration reaches 5–10 ms, the phase 0 of PD nodal cells has a relatively small slope. Figure 2.1 [6] shows the action potentials of the sinoatrial node (a) and working cardiomyocytes (b).



a - the sinoatrial node; b - working cardiomyocytes

Figure 2.1 – Potential action of cardiomyocytes [6]

The numbers in Figure 2.1 denote: 0 - the phase of rapid depolarization, 1 - the phase of initial repolarization, 2 - the phase of slow repolarization (plateau), 3 - the phase of rapid final repolarization, 4 - the phase of spontaneous diastolic repolarization.

The letters indicate: MP (mV) - membrane potential, P - threshold potential (critical level of depolarization), MDP - maximum diastolic potential, RP (TMPP) - resting potential, PD (TMPD) - amplitude of the action potential, P - reversal (overshoot) membrane potential, Δt - is the time of excitation from the CA site to the ventricles.

All these processes are related to the excitation of a single muscle fiber of the myocardium. Having arisen during depolarization, the impulse causes excitation of neighboring sections of the myocardium, which gradually covers the entire myocardium and develops as a chain reaction (Figure 2.2). Myocardial electrical excitation begins in a special zone of the right atrium - in the sinus node, which is the pacemaker, as it contains pacemaker cells. In a healthy person, the sinus node generates electrical impulses with a frequency of 60-90 beats per minute, which then propagate to the atria along the atrial conduction paths (along the Bachmann atrial bundle to the left atrium and along the lower branch of this bundle to the atrioventricular node, where there is a small pulse delay).

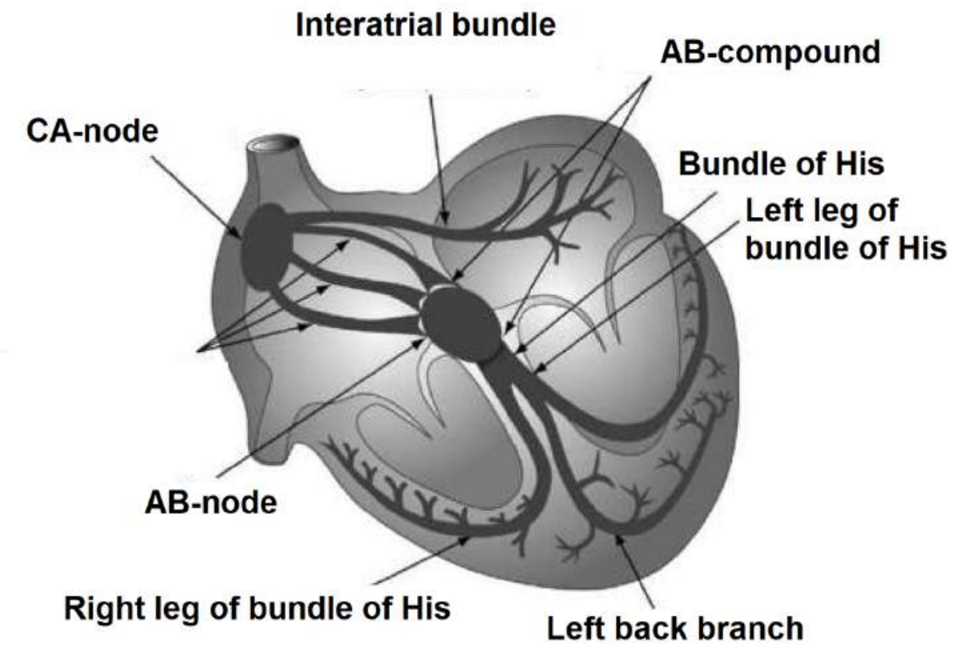


Figure 2.2 – The conduction system of the heart [2]

Further, the excitation goes to the trunk of the bundle of His, and then to its branch - to the right and left legs. The left leg, in turn, is divided into anterior and posterior branches. In the ventricular myocardium, impulses propagate through Purkinje fibers, which widely anastomose with each other.

Having seized the ventricles with excitement, the impulse that began the path from the sinus node fades because myocardial cells cannot remain excited for a long time. They begin the processes of restoration of their initial state before excitation. These processes are also recorded on the electrocardiogram.

2.2.2 Electrocardiogram (ECG)

The most common device for recording, visualizing and measuring bioelectric potentials of the heart is an electrocardiograph. It consists of an input device, an amplifier of biopotentials and a recording device. An electrocardiograph detects changes in the potential difference between two points in the electric field of the heart, in which the electrodes are installed, during excitation of the myocardium. This registration is called a lead.

Currently, 12 leads are used in clinical practice: three bipolar (standard) leads and nine - unipolar (three reinforced limb leads and 6 chest leads). With bipolar leads, two electrodes are connected to the electrocardiograph, with unipolar leads, one electrode (indifferent) is combined, and the second (trim, active) is placed at the selected point on the body. If the active electrode is placed on a limb, the lead is called unipolar, reinforced from the limb; if this electrode is placed on the chest - unipolar chest assignment.

The passage of an impulse along the conducting system of the heart is graphically recorded vertically in the form of peaks - the rises and falls of the curve line. These peaks are usually called the saw-teeth of the electrocardiogram and denoted by Latin letters [8]. If the saw-tooth amplitude of the QRS-complex from a standard electrocardiograph is more than 5 mm in recording paper, then the tooth is indicated by a capital (capital) letter, if less - a lower case (small) letter.

The time intervals between the same saw-teeth of adjacent cycles are called inter-cycle intervals (for example, P-P and R-R intervals), and between different teeth of the same cycle are called intra-cycle intervals (for example, P-Q and Q-T intervals). The intervals of the electrocardiogram between the waves are designated as segment. It's implements in describing properties of a interval – segment, such as duration, displacement towards the isoline or configuration (example of segments in ECG – the ST segment, or RT, the length of the segment from the end of the QRS complex to the end of the T wave). The general view of the electrocardiogram is shown in Figure 2.3.

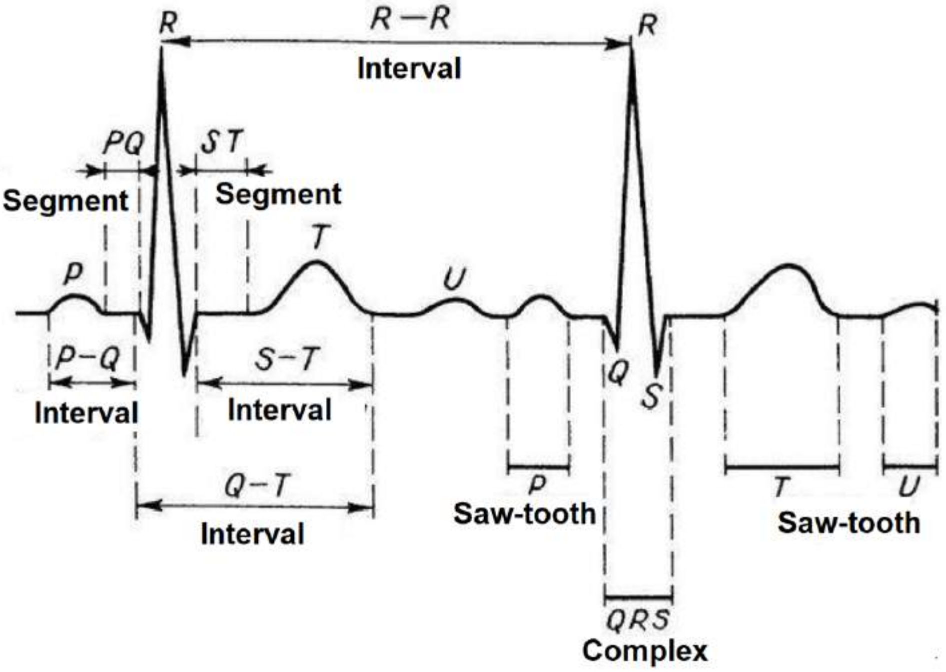


Figure 2.3 – General view of the ECG [2]

A typical human ECG consists of five positive and negative defections – saw-teeth, corresponding to the cycle of cardiac activity. They are designated by the Latin letters P, Q, R, S, T, and chest leads (pericardial) - V (V1, V2 V3, V4, V5, V6). Three teeth (P, R, T) are directed up (positive teeth), and two (Q, S) - down (negative teeth).

The amplitude of the teeth is measured in millivolts (mV), 1 mV corresponds to a deviation of 1 cm from the isoelectric line in standard calibrated paper. The width of the teeth and the length of the intervals are measured in seconds. The width of the saw-teeth and the duration of the intervals are evaluated by the lead, where these parameters have the largest value. Traditionally, all measurements of teeth and intervals are usually made in the second standard lead, denoted by the Roman numeral II.

The P wave reflects the period of atrial excitation, its amplitude varies from 0.05 to 0.25 mV, and the duration is 0.06-0.1 s. The PQ interval corresponds to the time of passage of excitation through the atria and atrioventricular connection to the ventricular myocardium. It varies in duration depending on age, body weight and rhythm frequency. Normally, the PQ interval is 0.12-0.20 s.

The QRS complex is recorded during ventricular arousal, and its duration reflects intraventricular conduction. The amplitude of the saw-teeth of the complex can vary significantly and depends on the position of the heart with respect to the chest leads. The first negative saw-tooth of the complex is called the Q wave, the other negative saw-teeth are called S. The R wave is always positive. The Q wave reflects the depolarization of the interventricular septum. The R wave is the highest in the ECG, it represents the depolarization of the apex of the heart, the posterior and lateral walls of the ventricles. The S wave reflects the excitation coverage of the base of the ventricles.

The ST segment takes the second most important place on the ECG curve. If the appearance of a pathological Q wave indicates necrosis of the heart muscle, then a pathological change in the ST segment may indicate damage to the heart muscle (damage segment). The ST segment reflects the ability (or inability) of the heart muscle at the same time be in state of excitement. In the first case, there is no potential difference and the ST segment is on the isoline or deviates from it by + - 0.1 mV, if there is a lesion, then the potential difference appears and the ST segment deviates from the isoline by a large amount. The T wave reflects the processes of repolarization of the ventricles. In leads from limbs in a healthy person, the amplitude of the T wave does not exceed 0.5-0.6 mV, and in chest leads 1.5-1.7 mV. The duration of the T wave varies from 0.16 to 0.24 seconds.

The R-R interval characterizes the time of one complete cardiocycle, or the time of one heartbeat. In the absence of pathologies in all the leads, standard ECG elements (impulses and intervals between them) are formed, repeating from one cardiocycle to another and reflecting the process of excitation and rest of different parts of the heart muscle. Actually, the ECG is a sequence of cardiocycles repeating at random time intervals. Each individual cardiocycle is defined by a quasi-determined function of complex shape, the sequential components of which have standard letter designations.

The informative parameters of ECG that determine the functional state of the cardiovascular system and are of interest for medical diagnostics are: amplitude, shape, polarity in different leads and repeatability in each cycle of all impulses, duration of P, Q saw-teeth, QRS complex and P-Q time interval, and the PP, QT, RR and PP intervals, as well as deviations from the isoline of the ST segment [3].

In pathology, these parameters can vary significantly, which makes it possible to use electrocardiography in the diagnosis of many heart diseases. Using electrocardiography, various heart rhythm disturbances, coronary insufficiency, various inflammatory and dystrophic lesions, and myocardial infarction are diagnosed [1].

High variability of the parameters of ECG (for example, fluctuations in the amplitude, duration of cardio pulses and intervals between them around average values, local surges and kinks) is observed even in the absence of pathologies and is associated with biological features of the formation and conduct of electrical impulses by body tissues, the location of electrodes and individual properties of a biological objects.

When taking bioelectric signals, the amplification system in the electrocardiograph contributes to a sharp amplification of not only useful signals, but also those minor interference of various types and origin, which are not always eliminated and constitute the main problem in the design and operation of such devices (signal to noise ratios less than 10 dB) In addition, the non-stationarity, complex structure and individual variability of the useful signal should be taken into account.

The presence of interference leads to distortion of the ECG and, accordingly, to the distortion of diagnostic signs. To assess the relationship between useful signal and the interference, Table 1.1 shows the amplitude-time parameters of the ECG corresponding to the norm, and Table 1.2 shows the main statistical parameters of the interference. An examination of the corresponding dependences shows that under favorable removal conditions, compensation for polarization and interference is not particularly difficult, and the interference is mainly represented as a random electromyography process, the spectrum of which has a significant overlap with the ECG spectrum.

The main power of the normal QRS complex is concentrated in the frequency range from 2 to 20 Hz, with a maximum at a frequency of about 15 Hz. In this case, one should take into account a possible change in the spectrum of the ECG depending on the morphology of QRS complexes and heart rate dynamics (with an increase in heart rate, the spectrum shifts toward higher frequencies). Studies show that with pathologies of the functioning of the heart, leading to a change in the shape of QRS complexes (for example, with polytopic ventricular extrasystoles), as well as with physical activity associated with an increase in heart rate, the overlap of signal and interference spectra increases [10].

Table 2.1 - Parameters of the elements of the normal ECG

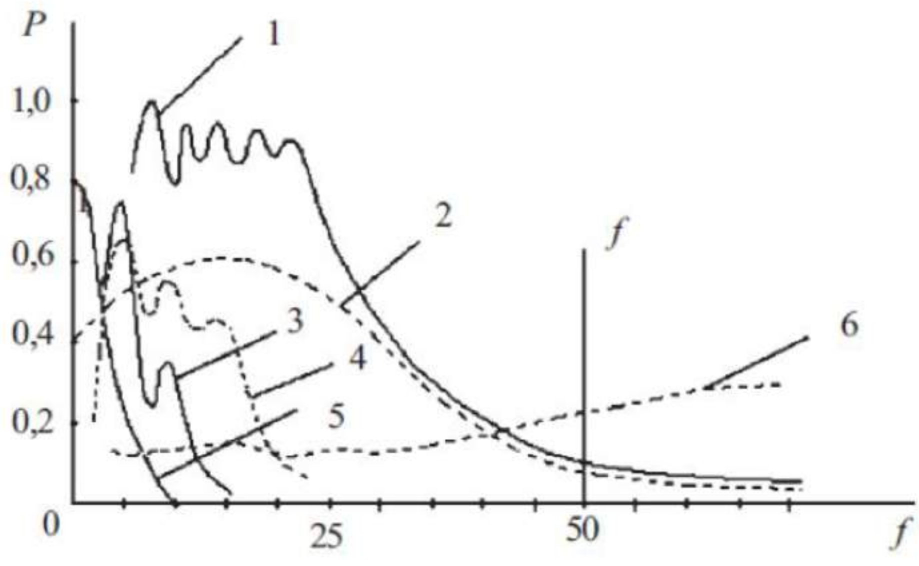
Parameter	Value parameter of element ECG						
	Saw-tooth P	Interval PQ	QRS-complex	Interval QT	Segment ST	Saw-tooth T	Saw-tooth U
Amplitude, mV	0 - 0.25	-	0.3 - 0.5	-	-	0.4 - 1	0 - 0.1
Duration, s	0.07 - 0.11	0.12 - 0.2	0.06 - 0.1	0.35 - 0.44	0.06 - 0.15	0.1 - 0.2	-

Table 2.2 - the Parameters of the additive interference accompanying the registration of ECG

Parameter	Value of parameter interference			
	Resting electromyography	Muscle tension electromyography	Crosstalk from the power powerline	Electrode polarization and displacement artifacts
Amplitude, mV	0.01 - 0.05	0.05 - 3	0 - 10^4	0 - 10^3
Duration, s	0 - 300	0 - 10^4	50 and harmonics up to 1000 Hz	0 - 30

The ratio of the frequency properties of the useful signal and interference is presented in Figure 2.4 in the form of graphs of the power spectral density for various components.

Therefore, ECGs are unsteady, complex, structured signals with cyclically repeating informative sections, in the form of bipolar pulses. Based on signs focused on local informative sections of the ECG, the state of the heart is evaluated in electrocardiography. The shape and parameters of informative sections of the ECG are diverse, variable and not always predictable. In addition, interference of various types and origin is inevitably present in the registration channel of the ECG, which is especially pronounced in conditions of prolonged registration and motor activity of patients.



The numbers in the figure indicate: 1 - ECG, 2 - QRS complex, 3 - P and T saw-teeth, 4 - artifacts of movement, 5 - drift of the contour, 6 - muscle noise

Figure 2.4 – Characteristics of the relative spectral power density of the ECG and noise [9]

A change in the shape of the ECG under the influence of interference leads to a distortion of diagnostic signs, which, in turn, can affect the correct diagnosis. Therefore, to reduce the likelihood of making erroneous or inaccurate diagnostic conclusions, it is necessary to qualitatively process the initial ECG, removing the interference component from the useful component. This leads to the need to develop new methods and means of eliminating interference.

In order to effectively combat interference distorting ECG, first of all, it is necessary to consider their sources, types and characteristics, causes of occurrence, as well as systematize interference according to significant signs. This will be addressed in Chapter 7. In the next two sections we simply provide introduction to ECG signal processing and filtering.

2.3 ECG Signal Processing

Electrocardiographic analysis was one of the very first areas in medicine where computer processing was introduced. Early work mostly dealt with the development of decision tree logic for ECG interpretation, mimicking the rules a cardiologist would apply. It soon became quite evident, however, that the outcome of computer interpretation was critically dependent on the accuracy of the measurements. As a result, the role of signal processing has become increasingly important in producing accurate measurements, especially when analyzing ECGs recorded under ambulatory or strenuous conditions. In addition, theoretical advances in signal processing have contributed significantly to a new understanding of the ECG signal and, in particular, its dynamic properties.

So far, no system offers a "universal" type of ECG signal analysis, but systems are designed to process signals recorded under particular conditions. It is, therefore, customary to speak of systems for resting ECG interpretation, stress testing, ambulatory ECG monitoring, intensive care monitoring, and so on. Common to all these systems is a set of algorithms which condition the signal with respect to different types of noise, extract basic ECG measurements of wave amplitudes and durations, and compress the data for efficient storage or transmission. The block diagram in Figure 2.5 presents this set of signal processing algorithms, i.e., filtering for noise reduction, QRS detection, wave delineation, and data compression; their respective descriptions define the scope of the present chapter. While these algorithms are frequently implemented to operate in sequential order, information on the occurrence time of a QRS complex, as produced by the QRS detector, is sometimes incorporated into the other algorithms to improve performance. The complexity of each algorithm varies from application to application so that, for example, noise filtering performed in ambulatory monitoring is much more sophisticated than that required in resting ECG analysis.

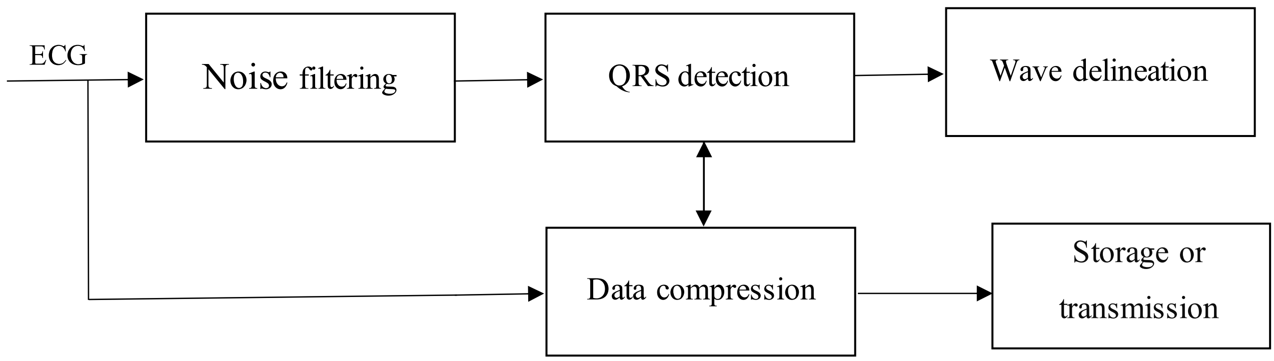


Figure 2.5 – Algorithms for basic ECG signal processing

The timing information produced by the QRS detector may be fed to the blocks for noise filtering and data compression (indicated by gray arrows) to improve their respective performance. The output of the upper branch is the conditioned ECG signal and related temporal information, including the occurrence time of each heartbeat and the onset and end of each wave.

2.4 ECG filtering

Considerable attention has been paid to the design of filters, which may have linear or nonlinear structures, for the removal of baseline wander and other artifacts see Chapter 4,, powerline interference. Removal of noise due to muscle activity represents another important filtering problem being much more difficult to handle because of the substantim spectral overlap between the ECG and muscle noise [10]. This circumstance is identical to the situation where the EEG signal is disturbed by muscle noise. In contrast to the EEG, muscle noise present in the ECG can be reduced whenever it is appropriate to employ techniques that benefit from the fact that the ECG is a recurrent signal. For example, ensemble averaging techniques used for noise reduction of evoked potentials, described in Chapter 4, can be successfully applied to time-aligned heartbeats for reduction of muscle noise.

The filtering techniques described in Chapter 4 are primarily used for preprocessing of the signal and have as such been implemented in a wide variety of systems for ECG analysis. It should be remembered, however, that filtering of the ECG, as with any other type of biomedical signal, is contextual and should be performed only when the desired information remains undistorted. This important insight may be exemplified by filtering for the removal of powerline interference. Such filtering is suitable in a system for the analysis of heart rate variability, whereas it is inappropriate in a system for the analysis of late potentials, as late potentials spectrally overlap with the interference.

A major concern when filtering out noise is the degree to which the QRS complexes influence the output of the filter. The QRS complex acts, in fact, as an unwanted, large-amplitude impulse input to the filter. Since linear, time-invariant filters are generally more sensitive to the presence of such impulses, filters with a nonlinear structure may be preferable. In order to assure that a filter does not introduce unacceptable distortion, its performance should be assessed by means of simulated signals so that distortion can be exactly quantified.

2.5 Discussion

Electrocardiography - study of heart activity based on registration and analysis of the electrical activity of the myocardium, pervasive heartbeat.

Electrocardiograph consists of an input device, an amplifier of biopotentials and a recording device. An electrocardiograph detects changes in the potential difference between two points in the electric field of the heart, in which the electrodes are installed, during excitation of the myocardium.

Electrocardiogram — is a signal which is displaying the contractile activity of the heart and can be easily recorded using surface electrodes placed on the limbs or chest.

A typical human ECG consists of five positive and negative defections – saw-teeth, corresponding to the cycle of cardiac activity. They are designated by the Latin letters P, Q, R, S, T, and chest leads (pericardial) - V (V1, V2 V3, V4, V5, V6). Three teeth (P, R, T) are directed up (positive teeth), and two (Q, S) - down (negative teeth). In pathology, these parameters can vary significantly, which makes it possible to use electrocardiography in the diagnosis of many heart diseases.

Parameters of ECG reflect:

- QRS complex is recorded during ventricular arousal, and its duration reflects intraventricular conduction;
- P wave – the period of atrial excitation;
- Q wave – the depolarization of the interventricular septum;
- R wave – depolarization of the apex of the heart, the posterior and lateral walls of the ventricles;
- S wave – the excitation coverage of the base of the ventricles;
- ST segment reflects the ability (or inability) of the heart muscle at the same time to be in state of excitement;
- R-R interval – the time of one complete cardiocycle, or the time of one heartbeat.

The informative parameters of the ECG that determine the functional state of the cardiovascular system and are of interest for medical diagnostics are: amplitude, shape, polarity in different leads and repeatability in each cycle of all impulses, duration of P and Q saw-teeth, QRS complex, etc.

3 ANALYSIS AND SYSTEMATIZATION OF INTERFERENCES IN ELECTROCARDIOGRAMS

3.1 Introduction

Chapter 3 contains an overview of the main types of interference arising during registration, and the reasons for their occurrence are considered. It describes a suite of methods, essential to any system which performs ECG signal analysis, developed for the purpose of noise reduction, heartbeat detection and delineation, and data compression.

3.1 – introduction.

3.2 – overview of different types of interferences and mistakes in diagnosis caused by presence of interferences in the signal.

3.3 – short overview of the chapter.

3.2 Interferences in the ECG.

There are various classifications of interference: by origin and structure, by energy spectrum, by the way of interaction with a useful signal, by probabilistic characteristics and other signs [9].

The interferences arising from the enhancement of biopotentials, according to the method of interaction with the useful input signal (in this case, ECG), are divided into additive and multiplicative. If the interference develops with the signal and their sum acts on the input of the receiver, then this interference is called additive. If the resulting signal is equal to the product of the interference and the transmitted signal, then the interference is called multiplicative.

Additive interference is determined by external influences on the signal transmission medium and does not depend on the values and form of the ECG, and also does not change its informative component.

Multiplicative or deforming interference can change the shape of the information part of the signal, depends on its values and on certain features in the signal, etc. Their value depends on the quality of the communication channel and the quality of service. There are no standard methods for compensating for multiplicative noise. However, if their nature is known, then a signal correction for the influence of these interference is possible.

Interference arising during registration of the ECG is diverse in origin and structure. This can be external interference, interference from a biological object and interference created by technical means.

Despite the variety of sources, most of the electrocardiographic interference can be combined into only a few groups from the point of view of their manifestation on a registered ECG (and from the point of view of methods for suppressing them). The main obstacles are:

- powerline interferences;
- muscle tremor;
- baseline wander;
- motion artifacts;
- impulse noise;
- high-frequency interferences.

3.2.1 Powerline interferences

The powerline interference looks like a jagged zero line with periodic repetition of the saw-teeths, which correspond to superposition of harmonics of different phases, with frequencies that are multiples of the frequency of voltage fluctuations in the power line. In Europe, the first harmonic with the highest power is 50 Hz. Although a typical form of powerline interference is known in advance, phase is unknown. Moreover, this interference in the general case is not an exact sinusoid, which is manifested by the presence in its spectrum of harmonics from the fundamental frequency.

The reasons for the appearance of powerline interference are poor contact electrodes with skin and improper organization of the research site. Figure 3.1 shows an example of an ECG with powerline interference.

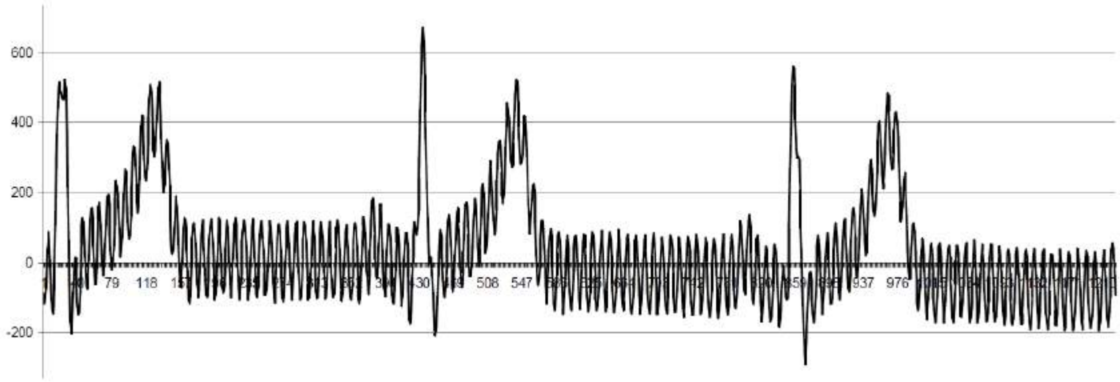


Figure 3.1 – A section of the ECG with powerline interference[2]

3.2.2 Muscle tremor

Muscle tremor looks like a random contour oscillating in a fairly wide range (30 ... 200 Hz). The reason of tremor is the electrical activity of tissues through which the impulse is transmitted (for example, skeletal muscles), the resistance of tissues, especially the skin, as well as the resistance at the input of the amplifier.

Muscle biopotentials are formed by the interference of many random incoherent potentials of individual muscles and are a random sequence of spiky pulses with an amplitude of 0.03…2 mV. The amplitude and frequency parameters of the tremor depends on the physical load and the location of the electrodes. As regards spectral and statistical characteristics of these noises, they are usually close to Gaussian noise with an uneven spectrum, Clifford considers them to be Gaussian flicker noise (the noise power is inversely proportional to the frequency) [10], and Pander models it as unsteady noise, described by a symmetric distribution with "heavy" tails (due to the presence of a pulsed component). Apparently, the latter characteristic is more consistent with reality [11] .

Tremor is superimposed on the ECG of patients with tremulous paralysis, chorea, tetany, parkinsonism. Fluctuations caused by muscle tremors are difficult to distinguish from atrial flutter.

Since skeletal muscles generate a signal independently of the pacemaker, tremor can be considered an additive hindrance. An example of an ECG with muscle tremor is shown in Figure 3.2.

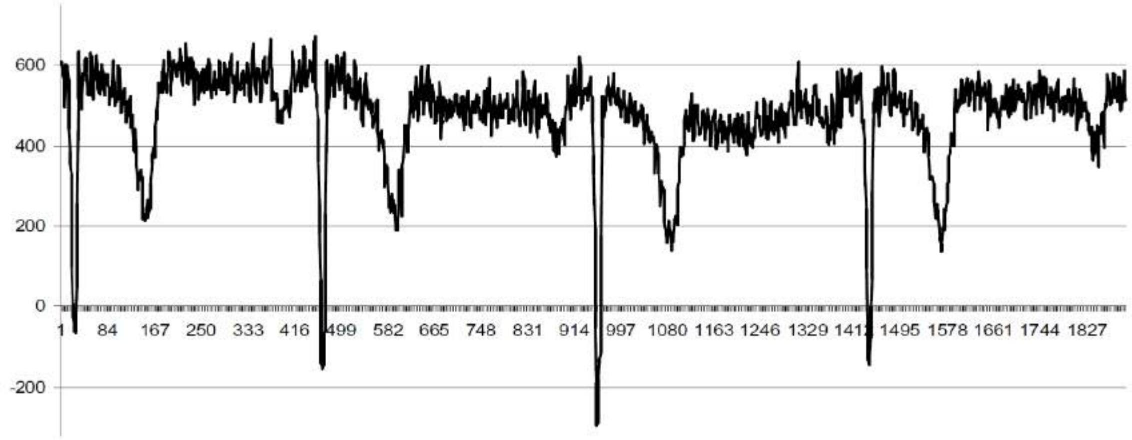


Figure 3.2 – Example of an ECG with muscle tremor [2]

3.2.3 Baseline wander

The baseline wander is a low-frequency oscillation with a typical content below frequency of content below 1 Hz.

Among the most significant reasons for the origin of the baseline wander drift of the ECG, it is worth highlighting [7]:

- motor activity of the patient, in particular respiration and the functioning of the human humoral system;

- change in the electrical properties of the interaction between the patient’s skin and the electrode due to disturbed contacts and polarization of the skin under the electrode.

The peculiarity of the baseline wander as a result of physiological influences is the randomness of its behavior and the presence of monotony, often covering several tens of electrocardiocycles.

The contour drift has the greatest influence on the analysis of low-frequency sections of the ECG, especially ST segments. In addition, the variability of the contour affects the accuracy of measuring the amplitude parameters of the teeth, because it is from the isoline that their amplitude is counted. Clifford characterizes this interference with “brown” noise (the noise power is inversely proportional to the square of the frequency) [2]. The stability of the contour depends on the presence of a sufficiently high input impedance of the amplification system and minimal skin resistance. Figure 3.3 shows an example of an ECG with baseline wander.

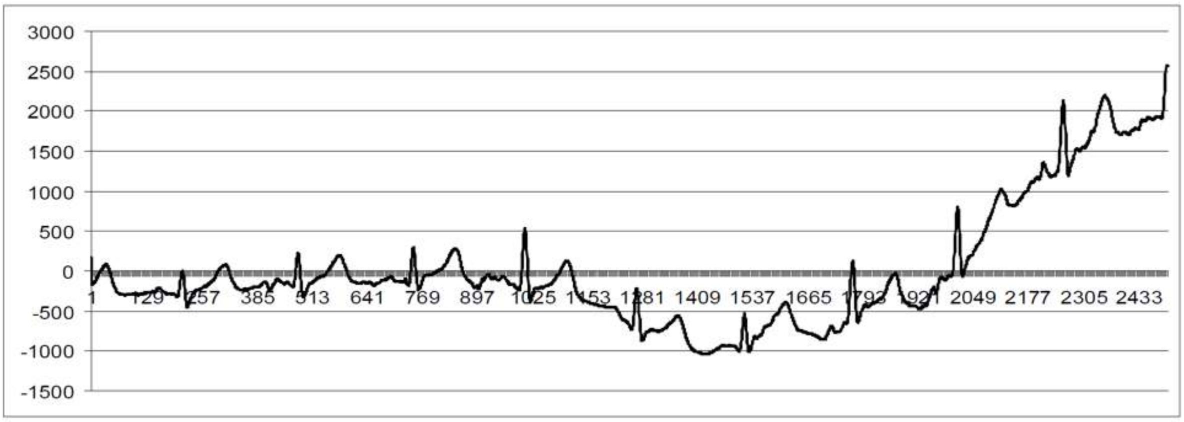


Figure 3.3 – An example of an ECG with baseline wander interference[2]

3.2.4 Motion artifacts

Motion artifacts appear as single or cyclic waves with a frequency in the range of 30-40 Hz. Single artifacts are associated with random mechanical influences on recording equipment, on electrodes in place of contact with skin, cough, hiccups, intestinal motility. Such artifacts in spectrum are very close to the spectrum of QRS complexes and are similar to ventricular extrasystoles, and therefore it is very difficult to differentiate them. Moreover, they pose a significant danger, since they interfere with the detection of QRS complexes, which can lead to incorrect calculation of heart rate, errors in the analysis of arrhythmias, and incorrect interpretation of the research results. At the peak of the load, motion artifacts can distort the ECG so much that it becomes unsuitable even for visual interpretation.

Cyclic waves are caused by movements of the patient's muscles or small changes in the position of the electrodes during a stress test or during free movement of patients.

3.2.5 Impulse interferences

Impulse interferences is an additive interference that is non-zero only at individual time intervals, separated by significantly longer intervals free from interference. Pulsed interference is a regular or random sequence of interfering pulses. Sources of impulse noise include atmospheric discharges, industrial installations, medical and household electrical appliances, etc [7].

3.2.6 High-frequency interferences

High-frequency noise of electrodes and amplifiers is a random noise of a physical (most often thermal) nature. We can distinguish "Johnson noise", shot noise and flicker noise [15].

Flicker noise is found in all active electronic components as well as some of the passive devices, and like shot noise, is associated with a DC current flow [9].

A characteristic property of this noise is that its magnitude decreases with frequency, and therefore, is sometimes referred to as 1/f noise. The PSD of flicker noise is often modeled by:

$$\tilde{i}_F^2 = K_F \frac{I_{DC}^{\gamma}}{f^{\beta}} \mathrm{A}^2/\mathrm{Hz} \tag{3.1}$$

The K_F, α and β in formula are constants particular to each device and its fabrication technology and I_{DC} is the DC current through the device.

Flicker noise generally dominates at low frequencies for a properly designed system while the white noise sources become dominant at higher frequencies. Flicker noise corner frequency, f_c is the frequency where the magnitudes of the white and flicker noises of a device are equal. The PSD of a system output is typically similar to the illustration in Figure 3.4.

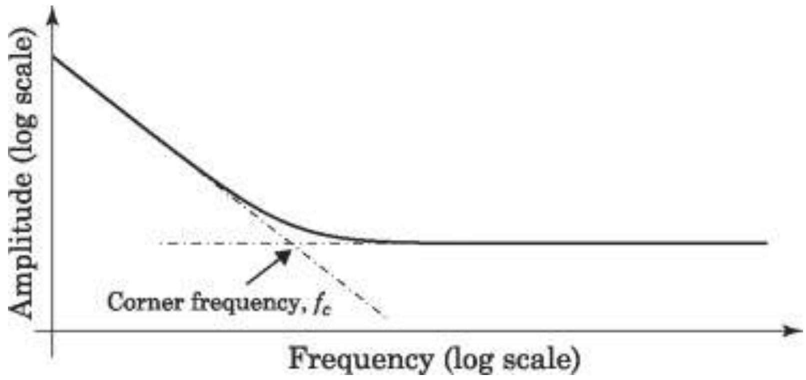


Figure 3.4 – The PSD of a system output

3.2.7 Errors in diagnosis caused by the presence of interferences in the signal

It should be noted that the spectra of all the above-described interference largely overlap with the ECG spectrum, which leads to difficulties in eliminating them.

According to the spectral characteristics (frequency region in which the main part of interference spectrum is located), all the interference is divided into the following types:

- high-frequency (HF) interference, which includes powerline interference and muscle tremor;
- low-frequency (LF) interference, which includes the contour drift and motion artifact.

In addition, there are other interferences (mainly HF instrumental and electrosurgical noises, some artifacts obtained during registration and processing of ECG, hardware interference, quantization noise and aliasing). However, their spectrum is very different from the spectrum of the ECG, therefore eliminating such interference is already no major problems.

All of the above interferences can cause of errors in measuring the parameters of the ECG and inaccurate detection of signal elements, which, ultimately, can lead to inaccurate or erroneous diagnostic conclusions. On the one hand, overdiagnosis is possible (the system accepts artifacts for various fictitious pathologies), and on the other hand, hypodiagnostics (skipping pathologies) caused by the masking effect of interference. Interference in some electrocardiographic studies (especially those related to patients' locomotor activity) is a serious problem for automatic analysis. The percentage of unsuitable (due to artifacts) to the analysis of the results of Holter monitoring is from 3.7 to 12.4% of studies [9]. The main difficulties in deciphering the results of Holter monitoring are usually associated with artifacts that mimic dangerous cardiac arrhythmias [16]. Even the term "Artifact pseudoarrhythmias" has appeared in the literature. Pseudoarrhythmias can seriously affect the results of the study and, ultimately, the establishment of the correct diagnosis and determination of the entire tactics of patient management.

Another major problem could be not eliminated or poorly eliminated isoline drift (“infarct-like electrocardiogram”), which can be accepted by the automatic analysis system as a false depression or ST segment elevation, and thereby lead to overdiagnosis of myocardial damage [7].

Table 3.1 shows the possible results of erroneous automatic diagnostics in the presence of various types of interference in the ECG. Table 1.4 shows the possible results of an erroneous diagnosis in the presence of distortions in the ECG. Tables 3.1 and 3.2 were prepared based on an analysis of the literature.

Table 3.1 - the results of erroneous automatic diagnostics in the presence of interference in the ECG

Type of interference	Interim results	Possible erroneous result diagnostics
Artifacts of movements (hiccups, coughing, tremors and other)	Ventricular extrasystoles, pathological QRS complexes. Atrioventricular condition measurement errors.	Hyperdiagnosis of heart rhythm disturbances
Muscle tremor	Atrial flutter. Atrioventricular condition measurement errors.	Hyperdiagnosis of heart rhythm disturbances.
Baseline wander	Blending or distorting an ST segment. Atrioventricular condition measurement errors.	Myocardial damage. Pericarditis. Myocarditis. Myocardial ischemia. Glycoside intoxication. Violation of repolarization. Hyperdiagnosis of coronary heart disease.
Powerline interference	Errors in detecting QRS complexes. Atrial flutter. Atrioventricular condition measurement errors	Hyperdiagnosis of heart rhythm disturbances.
Single impulse noises	Errors of detection of QRS complexes. Atrioventricular condition measurement errors	Hyperdiagnosis of heart rhythm disturbances.

Table 3.2 - Possible results of erroneous diagnosis in the presence of distortion in the ECG

Type of ECG distortion	Possible result of an erroneous diagnosis
Expansion of the QRS complex	Hypertrophy or dilatation (expansion) of the ventricles. Blockade of any part of the ventricular conduction system.
Reducing the amplitude of the QRS complex	Cardiomyopathy. Diffuse changes in the myocardium due to its defeat in many small focal heart attacks.
Increase in S-wave	Ventricular hypertrophy.
Decrease in the amplitude of the T wave	Damage to the myocardium
Change in the ratio of R and T saw-teeth	Diffuse changes in the myocardium due to its defeat in many small focal heart attacks.
Displacement or distortion of the ST segment	Myocardial damage. Pericarditis. Myocarditis. Myocardial ischemia. Glycoside intoxication. Violation of repolarization.

One of the main requirements for ECG processing algorithms, in addition to suppressing interference, is the preservation of the Q, R, S peaks and smooth extremes of P and T saw-teeth. In case of cardiac abnormalities in the ECG, there may be splits, small peaks, pathological saw-teeth and specific deformations of the QRS complex and ST segment, which are also important to maintain during processing. Therefore, the selection of the ECG filtering algorithm for dynamic properties must be carried out based on the goal of preserving the form of peaks, drops, kinks, smooth extremes, and for statistical characteristics of the relevant signal, while ensuring effective suppression of fluctuations caused by additive and multiplicative noise.

Therefore, it is important to use filters that not only effectively suppress noise, but also do not distort the signal.Accordingly, for the correct diagnosis of cardiovascular diseases and heart diseases, it is necessary to eliminate interference with the obligatory assessment of the quality of their elimination.

Given the wide variety of electrocardiographic interference, evaluating their negative effect on the useful signal and the result of automatic interpretation, requires a more detailed consideration and analysis of methods and the algorithms for suppressing interference in the ECG. In this work we will implement and compare several methods which are widely used for the elimination of baseline wander.

3.3 Discussion

3.3 In this chapter we have summarized the electrocardiographic interference.

3.3.1.1 Powerline interferences – superposition of harmonics of different phases, with frequencies that are multiples of the frequency of voltage fluctuations in the power line; looks like a jagged zero line with periodic repetition of the saw-teeths.

3.3.1.2 Muscle tremor – looks like a random contour oscillating in a fairly wide range (30 ... 200 Hz). The reason of tremor is the electrical activity of tissues through which the impulse is transmitted (for example, skeletal muscles), the resistance of tissues, especially the skin, as well as the resistance at the input of the amplifier.

3.3.1.3 Baseline wander is a low-frequency oscillation with a frequency of less than 1 Hz, caused by motor activity of the patient and change in the electrical properties of the interaction between the patient's skin and electrode.

3.3.1.4 Motion artifacts appear as single or cyclic waves with a frequency from a few Hz to 30-40 Hz. Single artifacts are associated with random mechanical influences on recording equipment, on electrodes in place of contact with skin, cough, hiccups, intestinal motility. Such artifacts in spectrum are very close to the spectrum of QRS complexes and are similar to ventricular extrasystoles. Caused by movements of the patient's muscles or small changes in the position of the electrodes during a stress test or during free movement of patients.

3.3.1.5 Impulse noise is a regular or random sequence of interfering pulses. Sources of impulse noise include atmospheric discharges, industrial installations, medical and household electrical appliances, etc.

3.3.1.6 High-frequency interferences includes powerline interference and muscle tremor, which includes motion artifact.

4 BASELINE WANDER REMOVAL

4.1 Introduction

Chapter 4 This chapter provides an overview of methods of filtering such as Linear, Time-Invariant Filtering and Forward-backward IIR filtering.

4.1 – introduction in chapter 4.

4.2 – removal of baseline wander summary.

4.3 – Time-Invariant Filtering overview.

4.4 – survey of forward-backward IIR filtering.

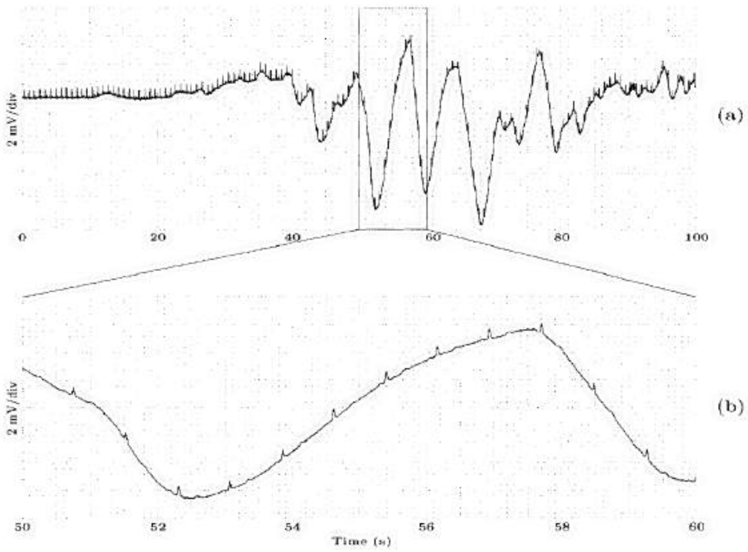
4.5 – overview LMS algorithm

4.6 – RLS filtering algorithm

4.7 – short discussion.

4.2. Characteristics of baseline wander

Removal of baseline wander is required in order to minimize changes in beat morphology which do not have cardiac origin. This is especially important when subtle changes in the "low-frequency" ST-T segment are analyzed for the diagnosis of ischemia, which may be observed, for example, during the course of a stress test. The frequency content of baseline wander is usually in the range below 0.5 Hz. However, increased movement of the body during the latter stages of a stress test further increases the frequency content of baseline wander. Patients unable to perform a traditional treadmill or ergometer stress test may still be able to perform a stress test by either sitting, running an ergometer by hand, or using a special rowing device. In such cases, baseline wander related to motion of the arms severely distorts the ECG signal. Figure 4.1 shows an example of the ECG with an large amount of baseline wander, the amplitude of the baseline wander is considerably larger than that of the QRS complexes. The bandwidth of such baseline wander is considerably larger than that caused by respiratory activity and perspiration. We will below describe the two major techniques employed for the removal of baseline wander from the ECG, namely, linear filtering and polynomial fitting. Linear filtering can be further divided into filtering based on time-invariant or time-variant structures.



(b) A close-up in time (10x) of the ECG signal framed in (a)

Figure 4.1 – (a) Electrocardiographic baseline wander due to sudden body movements [4]

4.3 Linear, Time-Invariant Filtering

The design of a linear, time-invariant, highpass filter to remove baseline wander involves several considerations. The most crucial are the choice of filter cut-off frequency and phase response characteristic. The cut-off frequency should obviously be chosen so that the clinical information in the ECG signal remains undistorted, while as much as possible of the baseline wander is removed [14]. Hence, it is essential to find the lowest frequency component of the ECG spectrum. In general, the slowest heart rate is considered to define this particular frequency component; the PQRST waveform is attributed to higher frequencies. During bradycardia the heart rate may drop to approximately 40 beats/minute, implying that the lowest frequency contained in the ECG is approximately 0.67 Hz. Since the heart rate is not perfectly regular, but always fluctuates from one beat to the next, it is necessary to choose a slightly lower cut-off frequency, approximately Fc = 0.5 Hz. If too high a cut-off frequency is employed, the output of the highpass filter contains an unwanted, oscillatory component which is strongly correlated to the heart rate [5].

The other crucial design consideration is related to the properties of the phase response and, consequently, the choice of filter structure. Linear phase filtering is highly desirable in order to prevent phase distortion from altering various wave properties of the cardiac cycle, such as the duration of the QRS complex, the ST-T segment level, or the end point of the T wave, see Figure 4.2. It is well-known that FIR filters can have an exact linear phase response, provided that the impulse response is either symmetric or antisymmetric [13, Ch. 4]. Figure 4.2 show that the original ECG (top panel) was processed with two filters having almost identical magnitude functions, but with either a highly nonlinear phase (solid line) or a zero-phase (dotted line). The signal produced by the filter with the nonlinear phase contains severely distorted ST-T segments (middle panel), while the zero-phase filter introduces virtually no distortion at all (bottom panel). The filter cut-off frequency was Fc = 0.5 Hz, and the sampling rate was F8 = 250 Hz. On the other hand, IIR filters introduce signal distortion due to the nonlinear phase response.

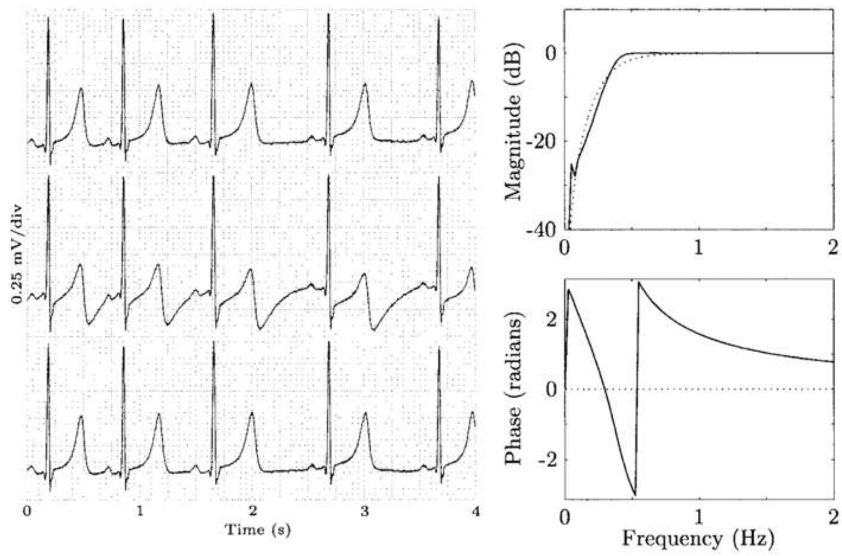


Figure 4.2 – Linear, time-invariant, highpass filtering and the effect of a nonlinear phase response [5]

If we assume that the filter cut-off frequency is F~ = 0.5 Hz, and the signal is sampled at a rate of F_s = 250 Hz, the corresponding discretized frequency becomes,

$$f_c = \frac{F_c}{F_s} = 0.002\ (rad) \tag{4.1}$$

which thus establishes that baseline wander removal must be treated as a narrowband filtering problem, i.e., only a fraction of the signal spectrum should be attenuated. Although a linear phase FIR, highpass filter can be designed in numerous ways, the result is invariably a filter with a very long impulse response. A straightforward approach to the design of a filter is to choose the ideal highpass filter as a starting point,

$$H(e^{iw}) = \begin{cases} 0,\ 0\ \leq |\omega| \leq \omega_c \\ 1, \omega_c \leq |\omega| \leq \pi \end{cases} \tag{4.2}$$

Since the corresponding impulse response has an infinite length,

$$h(n) = \frac{1}{2\pi}\int_{\omega_c}^{\pi} 1 \cdot e^{i\omega n} d\omega + \frac{1}{2\pi}\int_{-\pi}^{-\omega_c} 1 \cdot e^{i\omega n} d\omega = \begin{cases} 1 - \frac{\omega_c}{\pi},\ n = 0; \\ -\frac{\sin(\omega_c n)}{\pi n},\ n = \pm 1, \pm 2, \dots, \end{cases} \tag{4.3}$$

truncation can be done by multiplying h(n) by a rectangular window function, defined by

$$\omega_n = \begin{cases} 1,\ |n| = 0, \dots, L; \\ 0,\ otherwise \end{cases} \tag{4.4}$$

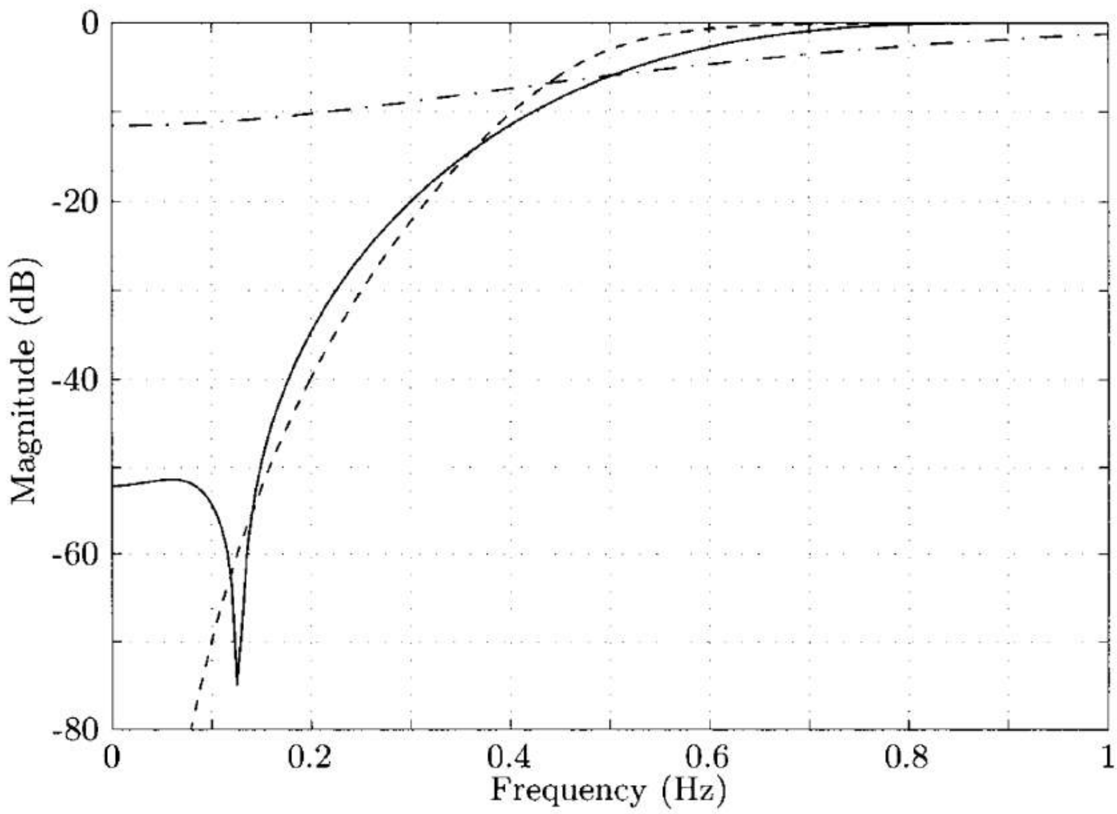
or by another window function if more appropriate depending on the required attenuation. Such an FIR filter should have an order 2L + 1 is around 1150 at least to achieve a reasonable trade-off between stopband attenuation (at least 20 dB) and the width of the transition band, see Table 4.1. Filter lengths required to achieve a certain stopband attenuation using the window method, in this case with a Keiser window. The cut-off frequency of the highpass filter is 0.5 Hz, the stopband interval is 0-0.3 Hz, and the sampling rate is 250 Hz.

Although the symmetry of the impulse response can be exploited to reduce the number of multiplications in the filter, a considerable number of multiplications is nevertheless required. The use of a filter with lower order, for example, 400, hardly provides any attenuation at all in the stopband, see Figure 4.3, where the frequency response of the forward-backward, fifth-order Butterworth filter is also displayed (dashed line). The cut-off frequency Fc was 0.5 Hz, and the sampling rate was 250 Hz.

Table 4.1 - Filter lengths required to achieve a certain stopband attenuation using the Keiser window.

Minimum stopband attenuation (dB)	Required filter length, 2L + 1
20	1142
30	1564
40	1884

Figure 4.3 – Frequency response for highpass filters designed with the



window method [5]

A number of techniques exist with which the above problem of filter complexity can be dramatically reduced, while preserving the linear phase property. These techniques include [2] :

- forward-backward IIR filtering;
- insertion of zeros into an FIR filter;
- sampling rate alteration.

In Section 4.4 we briefly describe the forward-backward IIR filtering technique. For more information on the other two, the interested reader can check [2].

4.4 Forward-backward IIR filtering

An IIR filter meets the magnitude specifications more easily with a much lower filter order due to the freedom of positioning its poles. However, this property is accompanied by a nonlinear phase response. The use of forward-backward filtering remedies this disadvantage since the overall result is filtering with a zero-phase transfer function. Implementation of such a filtering scheme involves three steps: processing of the input signal x(n) with an IIR filter h(n), time reversal of the filter output, and repeated processing with h(n), followed by time reversal of the doubly filtered signal to produce the output signal s(n), or, equivalently,

$$z_1(n) = h(n) * x(n) \tag{4.5}$$

$$z_2(n) = h(n) * z_1(-n) \tag{4.6}$$

$$s(n) = z_2(-n) \tag{4.7}$$

The overall effect of this scheme is established by determining the input output relationship in the frequency domain. Using the discrete-time Fourier transform of a real-valued signal x(n),

$$X\left(e^{iw}\right) = \sum_{n=-\infty}^{\infty} x(n)e^{-i\omega n}, \tag{4.8}$$

and the transform property

$$x(-n) \leftrightarrow X^*\left(e^{iw}\right)$$

(7.5)-(7.7) can be combined and written as

$$S(e^{iw}) = Z_2^*(e^{iw}) = H^*(e^{iw})Z_1(e^{iw}) =$$

$$= H^*(e^{iw})H(e^{iw})X(e^{iw})=$$

$$= |H(e^{iw})|^2 X(e^{iw}). \tag{4.9}$$

Thus, x(n) is processed with a filter whose magnitude function is $|H(e\hat{}(iw))|^2$ and phase function is zero, albeit that h(n) itself has a nonlinear phase response. The order of the overall filter is twice that of h(n). In order to exemplify forward-backward IIR filtering, the overall frequency response for a fifth-order Butterworth filter is shown in Figure 4.4 for fr = 0.5/250. It is evident that the frequency response is close to that of the FIR filter with a length of 1142, but with better attenuation of frequencies close to zero. The number of multiplications required for forward-backward IIR filtering is dramatically lower than that of straightforward FIR filtering. Forward-backward IIR filtering is primarily a scheme for off-line processing since the requirement of causality has to be relaxed when a time-reversed signal is processed. If one is willing to accept a relatively short time delay, this type of filtering can also be implemented in "almost" real time by processing successive, overlapping signal segments. The delay can be reduced by cleverly choosing the initial conditions of the forward-backward filters such that the initial transients at both ends of the filtered signal are minimized.

The application of forward-backward filtering to baseline wander removal becomes increasingly difficult at higher sampling rates, i.e., for 1000 Hz and higher, since the poles of the filter move closer and closer to the unit circle, or even outside, and the filter thus becomes unstable. Another potential disadvantage of forward-backward filtering is that this technique is not easily extended to handle time-variant filtering in which the cut-off frequency of the highpass filter varies in time.

4.5 Least Mean Squares algorithm

Least mean squares (LMS) algorithms are a class of adaptive filters used to mimic a desired filter by finding the filter's coefficients that relate to producing the least mean squared error signal (difference between the desired and the actual signal). It is a stochastic gradient descent method, in the sense that the filter is only adapted based on the error at the current time.

The (LMS) algorithms adjust the filter's coefficients to minimize the cost function. Compared to recursive least squares (RLS) algorithms, the LMS algorithms do not involve any matrix operations. Therefore, the LMS algorithms require fewer computational resources and memory than the RLS algorithms. The implementation of the LMS algorithms is also less complicated than the RLS algorithms. However, the eigenvalue spread of the input correlation matrix, or the correlation matrix of the input signal, might affect the convergence speed of the resulting adaptive filter [16].

4.5.1 Standard LMS

The standard LMS algorithm performs the following operations to update the coefficients of an adaptive filter:

1) Calculates the output signal $y(n)$ from the adaptive filter
2) Calculates the error signal $e(n)$ by using the following equation:

$$e(n) = d(n) - y(n) \tag{4.9}$$

3) Updates the filter's coefficients by using the following equation:

$$W(n+1) = W(n) + 2\,\mu(n)\,x(n)\,e(n) \tag{4.10}$$

where μ - is the step size of the adaptive filter

$W(n)$ –is the filter's coefficients vector

$x(n) -$ is the filter's input vector.

4.5.2 Normalized LMS

The normalized LMS (NLMS) algorithm is a modified form of the standard LMS algorithm. The NLMS algorithm updates the coefficients of an adaptive filter by using the following equation:

$$W(n+1) = W(n) + 2\,\mu \frac{x(n)}{||x(n)||^2} e(n) \tag{4.11}$$

We can also rewrite the above equation as the following equation:

$$W(n+1) = W(n) + 2\,\mu(n)\, x(n)\, e(n) \tag{4.12}$$

In the previous equation, the NLMS algorithm becomes the same as the standard LMS algorithm! except that the NLMS algorithm has a time-varying step size $\mu(n) = \mu/||x(n)||^2$ This adaptive step size can improve the convergence speed of the adaptive filter.

4.5.3 Sign LMS

Some adaptive filter applications require implementing adaptive filter algorithms on hardware targets, such as digital signal processing (DSP) devices, FPGA targets, and application-specific integrated circuits (ASICs). These targets require a simplified version of the standard LMS algorithm. The sign function, as defined by the following equation, can simplify the standard LMS algorithm.

$$\text{sgn}(x) = \begin{cases} 1; & x>0 \\ 0; & x=0 \\ -1; & x<0 \end{cases} \tag{4.13}$$

Applying the sign function to the standard LMS algorithm returns the following three types of sign LMS algorithms.

4.5.3.1 Sign-error LMS algorithm

Sign-error LMS algorithm applies the sign function to the error signal $e(n)$. This algorithm updates the coefficients of an adaptive filter using the following equation:

$$W(n+1) = W(n) + 2\,\mu\, x\,(n)\, sgn(e(n)) \quad (4.14)$$

Notice that when $x(n)$ is zero, this algorithm does not involve multiplication operations. When $e(n)$ is not zero, this algorithm involves only one multiplication operation $(2\,\mu)x\; x(n)$.

4.5.3.2 Sign-data LMS algorithm

Sign-data LMS algorithm applies the sign function to the input signal vector $x(n)$. This algorithm updates the coefficients of an adaptive filter using the following equation:

$$W(n+1) = W(n) + 2\,\mu\, sgn(x(n))\, e(n) \quad (4.15)$$

Notice that when $x(n)$ is zero, this algorithm does not involve multiplication operations. When $x(n)$ is not zero, this algorithm involves only one multiplication operation: $(2\,\mu)x\; e(n)$.

4.5.3.3 Sign-sign LMS algorithm

Sign-sign LMS algorithm applies the sign function to both $e(n)$ and $x(n)$. This algorithm oupdates the coefficients of an adaptive filter using the following equation:

$$W(n+1) = W(n) + 2\,\mu\, sgn(x\ (n))\ sgn(x(n)) \tag{4.16}$$

Notice that when either $e(n)$ or $x(n)$ is zero, this algorithm does not involve multiplication operations. When neither $e(n)$ or $x(n)$ is zero, this algorithm involves only one multiplication operations: just adding or subtracting 2 μ is required.

The sign LMS algorithms involve fewer multiplication operations than other algorithms. When the step size μ equals a power of 2, the sign LMS algorithms can replace the multiplication operations with shift operations. In this situation, these algorithms have only shift and addition operations. Compared to the standard LMS algorithm, the sign LMS algorithm has a slower convergence speed and a greater steady state error [5].

4.6 Recursive least squares filter

Recursive least squares (RLS) is an adaptive filter algorithm that recursively finds the coefficients that minimize a weighted linear least squares cost function relating to the input signals. This approach is in contrast to other algorithms such as the least mean squares (LMS) that aim to reduce the mean square error. In the derivation of the RLS, the input signals are considered deterministic, while for the LMS and similar algorithms they are considered stochastic. Compared to most of its competitors, the RLS exhibits extremely fast convergence. However, this benefit comes at the cost of higher computational complexity [17].

Compared to least mean squares (LMS) algorithms, recursive least squares (RLS) algorithms have a faster convergence speed and do not exhibit the eigenvalue spread problem. However, RLS algorithms involve more complicated mathematical operations and require more computational resources than LMS algorithms.

The standard RLS algorithm performs the following operations to update the coefficients of an adaptive filter:

1) Calculates the output signal $y(n)$ of the adaptive filter.

2) Calculates the error signal $e(n)$ by using the following equation:

$$e(n) = d(n) – y(n) \tag{4.17}$$

3) Updates the filter's coefficients by using the following equation:

$$W(n+1) = W(n) + x(n)\,K(n), \tag{4.18}$$

where $W(n)$ is the filter's coefficients vector and $K(n)$ is the gain vector.

The main goal of RLS filter is to minimize a cost function C by appropriately selecting the filter coefficients w_n, updating the filter as new data arrives. The error signal e(n) and desired signal, d(n), are defined in the negative feedback diagram below (figure 4.4),

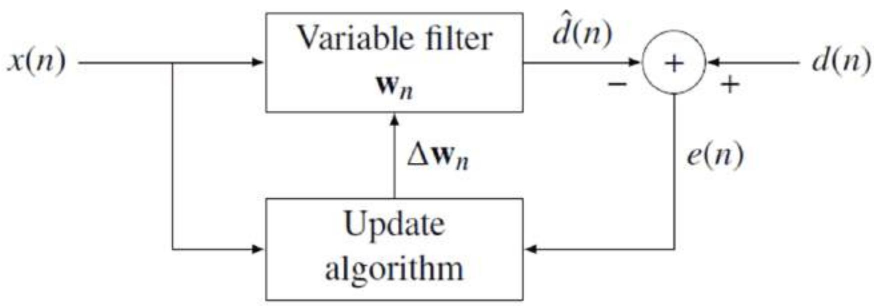


Figure 4.4 – Adaptive RLS filter [19]

To allow for continuous operation, and thus actual implementation, the solution can be computed in recursive form. The output of the FIR filter is computed as:

$$y(n) = d(n)w(n-1) \tag{4.19}$$

Since the filter output now incorporates previous samples into the calculation and an a priori estimation error. This is generally different from the a posteriori estimation error, e(n), used in the LMS algorithm.

4.7 Discussion

Baseline wander is a low-frequency artifact in electrocardiogram (ECG) signal recordings of a subject. BW removal is an important step in processing ECG signals, because BW makes interpretation of ECG recordings difficult. The main cause of BW in the ECG signal is movement and respiration of the patient. Baseline wander is usually in the range below 0.5 Hz. Removal of baseline wander is required in order to minimize changes in beat morphology which do not have cardiac origin. This is especially important when subtle changes in the "low-frequency" ST-T segment are analyzed for the diagnosis of ischemia.

Major techniques for removal of baseline wander from the ECG:

- linear, time-invariant filtering;
- forward-backward IIR filtering.

The cut-off frequency should obviously be chosen so that the clinical information in the ECG signal remains undistorted while as much as possible of the baseline wander is removed. it is essential to find the lowest frequency component of the ECG spectrum. The slowest heart rate is considered to define this particular frequency component; the PQRST waveform is attributed to higher frequencies. If too high a cut-off frequency is employed, the output of the highpass filter contains an unwanted, oscillatory component which is strongly correlated to the heart rate.

IIR filter meets the magnitude specifications more easily with a much lower filter order due to the freedom of positioning its poles. This property is accompanied by a nonlinear phase response.

The linear phase implementation involves three steps: processing of the input signal x(n) with an IIR filter h(n), time reversal of the filter output, and repeated processing with h(n), followed by time reversal of the doubly filtered signal to produce the output signal s(n). The overall effect of this scheme is established by determining the input output relationship in the frequency domain.

Forward-backward IIR filtering is primarily a scheme for off-line processing, since the requirement of causality has to be relaxed when a time-reversed signal is processed. If one is willing to accept a relatively short time delay, this type of filtering can also be implemented in "almost" real time by processing successive, overlapping signal segments. The delay can be reduced by cleverly choosing the initial conditions of the forward-backward filters, such that the initial transients at both ends of the filtered signal are minimized.

LMS algorithm has established itself as the workhorse of adaptive signal processing for two primary reasons: computational efficiency and robust performance. However, for signals with a large spectral dynamic range, the LMS has a non-smooth and slow rate of convergence. In addition, if the signal is also non-stationary (e.g., speech and audio signals), then the LMS can be an unsuitable adaptation method. LMS algorithms are known as slowly converging algorithms. The speed of convergences define the number of signal intervals that are necessary to obtaining reliable filter coefficients. [16]

RLS algorithm have much better starting convergence properties but is more complex and for that reason, not so suitable for low computational devices. RLS method, has better convergence rate and less sensitivity to the eigenvalue spread than LMS. [17]

5 RESULTS

5.1 Introduction

This chapter presents the results for the validation process of these techniques such as Linear Time-Invariant Filtering and Forward-backward IIR filtering.

5.1 – introduction.

5.2 – removal of baseline wander.

5.3 – short discussion.

5.2 Performance of denoising algorithms

During the implementation process, all the validation tests were performed in a x86 platform without any constraint in terms of memory consumption and computation cost. The implementation was validated using the Physionet MIT-BIH Arrhythmia Database (mitdb) [15].

Noisy ECG signals were created by adding artifacts to clean the ECG signals. The clean ECG signal was 1 minute duration of the signal record 100 from the MIT-BIH database. All artifacts were also obtained from the MIT-BIH database. The noisy ECG signals is illustrated in Figure 5.1. Once the noisy ECG signals were created through adding the baseline wander interference to clean signal, they were fed into main MATLAB program. In the main program, performance of LMS, NLMS, KLMS, NKLMS and RLS algorithms on the noisy ECG signals were tested. For achieving the best result in filtering in experimental way were manually selected parameters for input, such as stepsize in range from 0.1 to 250 and mu in range from 1e-10 to 1, respectively. This process was done for each LMS, NLMS, KLMS and NKLMS algorithms, through changing methods to calculate filter weights. Method to calculate filter weights, specified the following:

- 'LMS' – Solves the Weiner-Hopf equation and finds the filter coefficients for an adaptive filter;

- 'Normalized LMS' – Normalized variation of the LMS algorithm;

- 'Sign-Data LMS' – Correction to the filter weights at each iteration depends on the sign of the input x;

- 'Sign-Error LMS' – Correction applied to the current filter weights for each successive iteration depends on the sign of the error, err;

- 'Sign-Sign LMS' – Correction applied to the current filter weights for each successive iteration depends on both the sign of x and the sign of err.

Choosing optimal parameters for designed filter is important. In ECG filtering this parameters are calculated through approximation, manually best performance by experimenting. For baseline wander removal – the smaller the step-size is, the better filter will perform. As a disadvantage, in this case filter will converge, but filtered signal will be deprived of more artifacts.

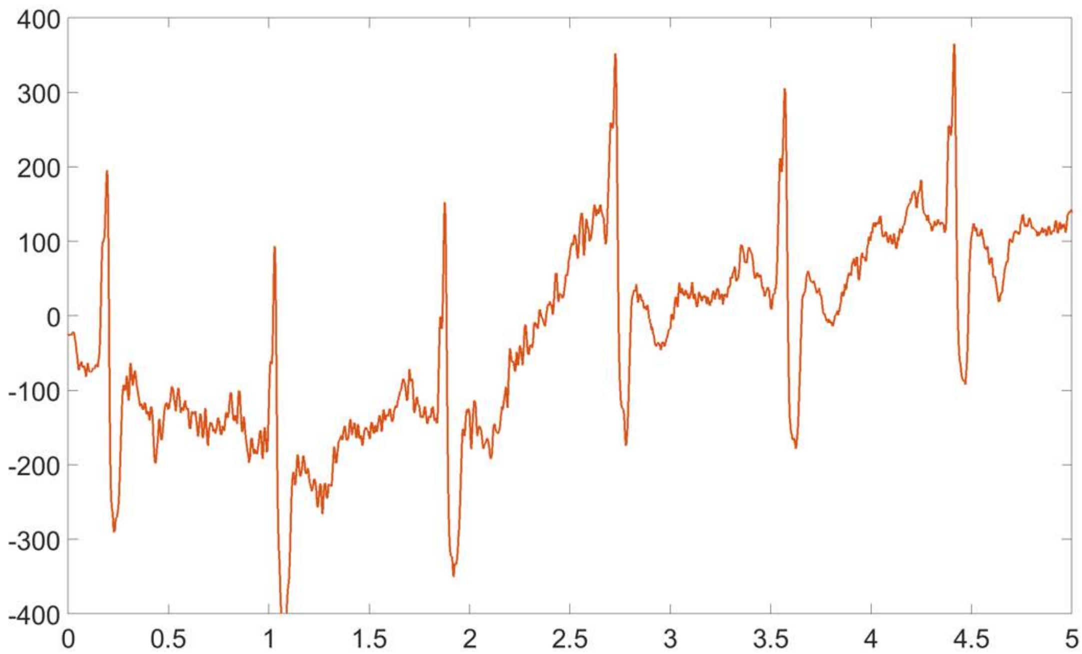


Figure 5.1 – ECG signal with baseline wander interference

The mean squared error (MSE) of an estimator (a procedure for estimating an unobserved quantity) measures the average of the squares of the errors—that is, the average squared difference between the estimated values and the actual values. MSE is a risk function, corresponding to the expected value of the squared error loss. That MSE is almost always strictly positive can be attributed to either randomness, or the fact that the estimator does not account for information that could produce a more accurate estimate [7].

The speed with which the filter converges to the optimal state, known as the convergence speed, depends on multiple factors such nature of the input signal, choice of the adaptive filter algorithm, and step size of the algorithm. Inputs in LMS filter which were used: mu and stepsize.

Setting the step size of μ(mu) needed for convergence of the normalized LMS equations $0<\mu<2$.

Stepsize – adaptation step size factor, specified as a non-negative scalar. The step size increases or decreases as the mean-square error increases or decreases, allowing the adaptive filter to track changes in the system as well as produce a small steady state error.

Small step size ensures a small steady state error between the output y and the desired signal d. If the step size is small, the convergence speed of the filter decreases. To improve the convergence speed, increase the step size. Note that if the step size is large, the filter can become unstable:

- too large step size gives a fast response to plant changes but results in a large excess mean square error (MSE), and may even cause loss of convergence;
- too small step size degrades tracking capabilities of the algorithm.

An optimal step size, giving a trade-off between the speed of convergence and residual error, depends on the power of the input data.

Therefore, the main, commonly used modification of the LMS algorithm is a normalization of the step size. This leads to the normalized LMS (NLMS) algorithm, in which the step size is scaled (divided) by an estimated power of the input data. However, even the NLMS algorithm requires a "base" step size choice[7].

We have applied denoising methods overviewed in Chapter 4 on ECG signal with artifacts. The parameters for implemented filters and the normalized MSE(NMSE) are shown in Table 5.1.

Table 5.1 - Summary of algorithm differences

Denoising method	Parameters			NMSE before applying filters
	mu	Stepsize	NMSE	
Highpass filter	-	-	0.1698	1.1847
Standard LMS	0.0000000005	200	0.1929	
Normalized LMS	0.0191	216	0.2083	
Sign-Data LMS	0.00000074	202	0.2083	
Sign-Error LMS	0.0000001	200	0.2120	
Sign-Sign LMS	0.0000195	199	0.2201	
RLS	-	11	0.0758	

Figure 5.2 showing the results of modeling an ECG signal after applying highpass filter.

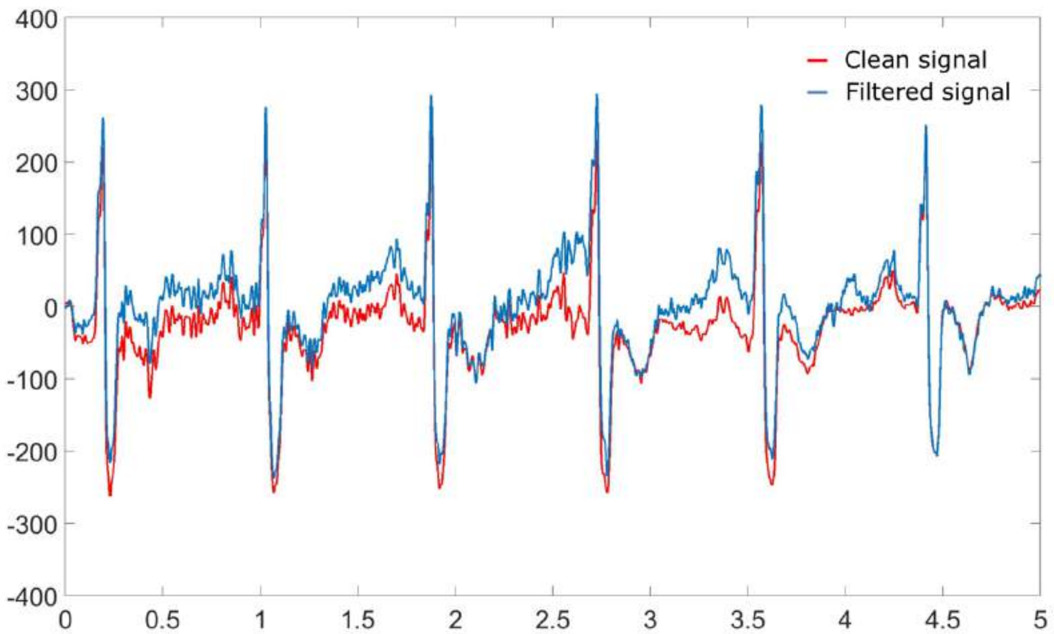


Figure 5.2 – Filtered ECG signal with highpass filter.

The signals shown in Figures 5.3 and 5.4 correspond to the outputs the adaptive filters. The adaptive filters used are the LMS and RLS algorithms respectively. We have also considered other types of adaptive filters: NLMS, SDLMS, SELMS, SSLMS. But they showed similar results a LMS filter, shown in Figure 5.3. This result also could be overviewed in Table 5.1.

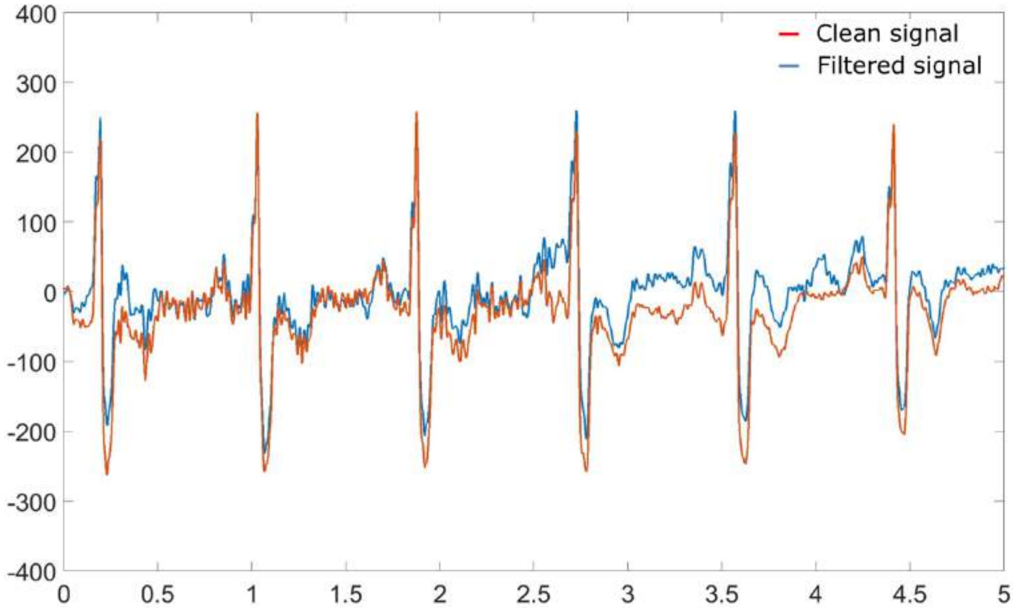


Figure 5.3 – Filtered ECG signal with LMS filter

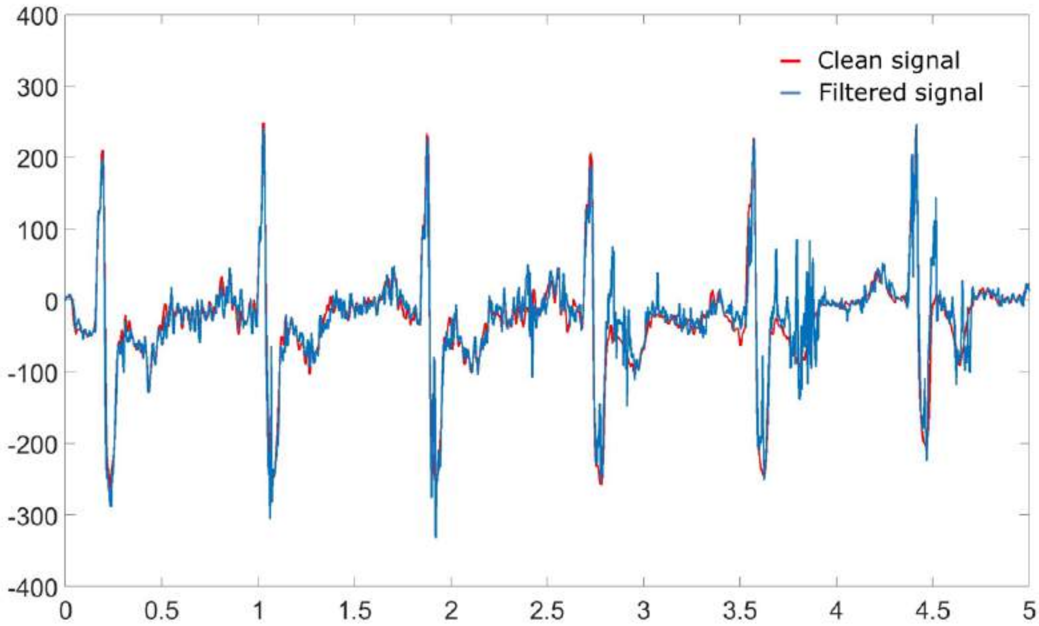


Figure 5.4 – Filtered ECG signal with RLS filter

5.3 Discussion

Based on results it can be seen that the RLS algorithm showed best result in filtering. Even that after RLS filtering signal received other type of noise, all peaks of the ECG are not distorted, it means that main information from ECG signal can be used in diagnosing. However, even though this program is designed for online computation, it still takes a while to compute, as discussed in Table 5.2. As for improving the results, one can implement a variable step-size algorithm which can help on faster convergence of algorithm at the start.

Table 5.2 - Summary of LMS and RLS algorithms

Algorithm	Data modeling	Computation	Simplicity
LMS	Linear	Fast	Simple
Normalized LMS	Linear	Fast	Simple
Sign LMS	Linear	Fast	Moderate
RLS	Linear and non-linear	Moderate	Moderate

6 ECONOMIC CHAPTER

Currently, electrocardiography is used in all stages of medical examination of cardiovascular diseases: in prevention, diagnosis and therapy. Noise reduction, elimination of technical deficiencies in recording and separation of the desired physiological process from interfering processes – is an integral part of working with an electrocardiographic signal.

Clean signals are always masked by noise and interference and can only be detected after proper signal processing. Automatic analysis of the electrocardiosignal is a complex problem. Existing computer diagnostic systems do not provide the required reliability of the results. This is due to the fact that the signal is a realization of a corrected random process, which is non-stationary, and is a mixture of a deterministic component and numerous types of noise.

For an accurate diagnosis of diseases, it is necessary to have the most pure and undistorted signal by interference. Processing of cardiac parameters is also possible manually, however, their automatic calculation using a computer gives great advantages and requires less time.

The actual problem today is the reliability and availability of software for cardiographic devices. There are known developments of numerous foreign firms, cardiographs, which perform these operations, but their cost is very high. In this regard, this Diploma project was devoted to the development of filters, which will perform the function of cleaning the signal from noise in the environment of the computer mathematical system MATLAB.

MATLAB (Matrix Laboratory) is a universal software environment for performing research and technical calculations of almost unlimited complexity. The advantage of the MATLAB system is that MATLAB procedures and functions can not only be used, but also modified. Subsequently, the user has the opportunity to introduce new commands or functions into the system, create their own programs and procedures, or adapt existing procedures in accordance with their needs.

In connection with the existing conditions and needs of the market, this Diploma project was developed, which will allow the transition to the release of the software product developed in the main part of the diploma project.

6.1 Economic analysis of the project

In connection with the existing conditions and the needs of the market it developed this project. This project will allow to proceed to the release of the software product developed in the main part of the diploma project. A description of the project idea is given in Table 6.1.

Table 6.1 Description of the project idea

Idea content	Directions of application	Benefits for consumers (users)
Filtering the noise-distorted electrocardiography signal. Removing baseline wander from ECG signal .	- Diagnosis ; - therapy ; - monitoring the patient's conditions - the study of diseases of cardiovascular system - statistical research	- High processing speed ; - low cost; - ease of use; - flexibility of the method ; - the possibility of modification and adaptation ; - portability and mobility of the method; - possibility of implementation in the context of mobility.

Table 6.1 described the idea of an algorithm for removing noise from an electrocardiogram signal. This should be a universal method to combat the distortion of the electrocardiogram signal, namely, the removal of baseline drift. This method has great potential in the interest of users for its quality of results after using this method, price and ease of use.

To implement a project, it is necessary to determine its characteristics, strengths and weaknesses in comparison with competitors. Analysis of the potential market is shown in table 6.2.

Table 6.2 - Previous characteristics of the potential market

No.	Market condition indicators (name)	characteristic
1	Main competitors	By ompyuterny electrocardiograph clickecg-hd, CARDIOLINE (and waist)
		By ompyuterny ECG Fukuda Denshi Cardimax FX-8222 (Japan and I)
		By ompyuterny ECG SE-1201, Edan (China)
2	Dynamics	growing
3	Access restrictions	no
4	Specific requirements for standardization and certification	- manufacturing process must ensure that the metrological characteristics are met. - technical documentation for the product of production should mystify: - results of design calculations; - risk analysis; - fulfillment of performing research and technical tests

Based on the analysis of the table, it was concluded that the market is attractive for entry.

In the future, potential customer groups were identified, their characteristics, and an indicative list of requirements for the product for each group was formed. The analysis results are shown in Table 6.3.

Table 6.3 - Previous characteristics of potential customers

Demand of the market	Target audience (target market segments)	Behavior of these different potential target customer groups	Customer (Users) requirements
Denoising the ECG signal from the baseline wander noise with no loss of accuracy	- medical institutions, cardiac centers, hospitals, clinics, dispensaries, health centers. - people suffering from cardiovascular diseases, carriers of built-in pacemakers, people who have undergone surgery or severe treatment, patients at risk, everyone who looks after their health; - educational and research centers	A target group that wants to receive a noise-free ECG signal without or with minimal loss in accuracy, for an accurate diagnosis	- signal processing speed; - high accuracy; - ease of use; - low cost; -energy efficiency; - operational safety; - ability to remain relevant over a long period of time; -existence of development certification; -quality of the interface; - mobility; - simplicity of the interface; - availability of a customer support hotline; - high accuracy.

The target audience of this project was described in table 6.3. The target audience is large, because electrocardiography is present in almost all stages of interaction between patients and medical institutions. This project may interest their speed and signal processing and high accuracy.

After identifying potential client groups, a SWOT analysis of the project was carried out based on the project characteristics that were provided in the previous tables. The SWOT analysis results are shown in Table 6.4.

Table 6. 4 - SWOT- analysis

Strengths:	Weak sides:
- convenient use; - ease of use; - high level of signal purification from interruptions with minimal loss in quality; - execution speed.	- need to purchase the MATLAB application package; - presence of losses in the resulting signal after use the method; - the complexity of the implementation.
Capabilities:	Threats:
- ability to work with recorded and transmitted signals; - Improved signal processing speed; - possibility of modifying the method to improve filtration.	- increase in the cost of maintenance required for the operation of the system; - consumers need different functionality; - competition; - emergence of new, more efficient algorithms.

In table 6.4 the SWOT analysis of the project was given. Strengths are described, such as user-friendly interface and implementation features, the main drawback is described, namely the high complexity of implementation. Opportunity and threat information is provided. The main feature is the ability to modify the filter. The main threats have traditionally been competition and changes in user needs.

Developing a market strategy as the first step involves defining a market coverage strategy – a description of the target groups of potential consumers are given in Table 6.5.

Table 6.5 - Selection of target groups of potential consumers

Description of the profile of the target group of potential customers	Willingness consumers perceive product	Estimated demand within the target group (segment)	Intensity of competition in the segment	Simplicity WMOs row in segment
- medical Institutions; - research Centers.	method which will denoise ecg signal from baseline wander type of noise	high	there are three types of competitors that provide similar but more expensive and more difficult-to-use solutions	- speed of denoising; - easy to use interface; - high accuracy.
Selected target group: Medical institutions and educational and research centers.				

Table 6.5 described the main target groups of potential consumers. The approximate demand within the target group was given, the intensity of competition in the segment and the approximate difficulty of entering the market for this project were described. The main target groups have been selected medical institutions and research centers, which may be interested in our methods of dealing with signal noise.

Let's calculate the wages of all categories of workers directly involved in the process of carrying out all stages of research work. The amount of wages is calculated on the basis of the employment of performers for individual stages of work and the average daily earnings for each category of personnel. The deductions for the unified social contribution (ERU) are 22%. The calculation results are listed in tables 6.6.

Table 6.6 - Composition, number and payroll

position	Keel of bones	Posadoviyoklad, UAH	Tariff rate for the category of	Effective fund of working time,	Bonus percentage to salary,%	Prize amount , UAH	Salary, UAH	Employment, days	Total salary, UAH	ESC, UAH
1	2	3	4	5	6	7	8	9	10	11
Lead engineer	1	8019	40.5	9	15	1202.85	9221.85	36	13122	2886.84
Engineer	1	6514.2	32.9	9	20	1302.84	7817.04	27	7020	1544.4
Economics consultant	1	5300.46	26.77	9	5	265.02	5565.48	14	3372.6	741.97
Occupational safety consultant	1	5300.46	26.77	9	5	265.02	5565.48	10	2409	529.99
Total	4	25134.12	-	-	-	3025	28025	-	25923.6	5703.19

The article for determining the cost of materials includes the cost spent on equipment and system support costs. These costs are one-time and no subsequent costs are planned, since the final product is software. Initial data and calculation of the cost of materials are entered in table 6.7

Table 6.7 - Calculation of material costs

Material costs	Quantity, pcs	Unit price, UAH	Total cost, UAH
1	2	3	4
Macbook Pro notebook 13 A 1502	1	20,000	20,000
MATLAB license + additional package	1	75000	75000
Microsoft Office 2019	1	2200	2200
Total			97200

To calculate the cost of electricity, we use the formula:

$$E = (P_{eq} * F_{ef} \cdot K_{u} * Pr) /CPA \quad (6.1)$$

where :

P_{eq} – is the installed capacity of the equipment power collectors, kW;

F_{ef} – effective fund of operating time of this type of equipment, h;

K_{u} – is the utilization factor of power plants in terms of power and time (0.8)

Pr - Price of 1 kWh of electricity (2.68 UAH (VAT included))

CPA = 0.8

$$F_{ef} = a * b\left(1 - \frac{c}{100\%}\right) \quad (6.2)$$

where :

a – quantity of shifts;

b– shift duration;

c – percentage of lost working time for scheduled repairs (10 %).

$$F_{ef} = 36 * 9\left(1 - \frac{10}{100\%}\right) = 291{,}6\ (h)$$

$$E = \frac{0{,}45 * 291{,}6 * 0{,}8 * 2{,}68}{0{,}8} = 351{,}67\ (\text{UAH})$$

Initial data and results calculated ku consumed services will bring but in and table 6.8.

Table 6.8 - Calculation of the cost of consumed services

Type of service	Installed power P_{eq}, kW	Duration of use F_{ef}, h	The tariff per kilowatt- hour Pr,UAH	Energy cost, UAH
Power supply	0,45	291,6	2,68	351,67

Depreciation is defined as the product of the book value of the fixed asset and the depreciation rate in accordance with 14.1.138 of the Tax Code of Ukraine, according to which the cost criterion for fixed assets with a value of up to UAH 20,000. Therefore, those material assets, the useful life of which is more than a year, but the cost is less than or equal to UAH 20,000, are recognized as low-value non-current tangible assets (hereinafter - MNMA). For this in 138.3.3 TC is provided group 11 "Low-value non-current tangible assets", the term of use for which is not determined. Therefore, depreciation is charged on a 50/50 basis (upon receipt - 50% and 50% - upon write-off) or 100% upon receipt. In this project, a 100% depreciation method was chosen.

Depreciation charged on intangible assets is calculated according to this principle. The initial cost of intangible assets was 77200 UAH. The useful life is 10 years (120 months). The annual depreciation rate in this case is 10% (100%: 5 years).

The annual depreciation amount will be equal to UAH 7,720 (UAH 77,200 x 10%); the monthly depreciation amount is 643.33 UAH.

Raw data and the calculation of depreciation will bring but in and blitz 6. 9

Table 6.9 - Depreciation calculation

Fixed assets group	Amortization period, month	Depreciation rate,%	Initial cost , UAH	Annual amount depreciation, UAH
Laptop Macbook Pro 13 A1502	-	100	20 000	20000
Intangible assets	120	10	77200	7720
Total				27720

The item "Routine repair of equipment" is taken equal to 2% of the balance sheet value of the equipment and amounts to UAH 400 . The item "Other expenses" is taken equal to ten percent of labor costs and amounts to approximately UAH 2600 . The estimated cost estimate are in Table 6.10

Table 6.10 - Cost estimate

Calculation Items	Cost, UAH
Equipment costs	20 000
Expenses for system software	77200
Power supply	351,67
Total	97493
Wages of employees	25923.6
Contributions to social events (ERU)	5703.19
Depreciation	27720
Expenses for the maintenance and operation of fixed assets current repair	400
Production cost	254 791,46
Other expenses	2600
Total cost	257 391,46

6.2 Conclusions

In this section, the analysis of the software product as a startup project was carried out. It can be noted that the project has the possibility of commercialization, because the market for the provision of services in the processing of biomedical signals using recommender systems is dynamically developing, new algorithms for removing obstacles are being created, which, in turn, stimulate the demand for various auxiliary means to speed up the work and optimize existing algorithms and material support.

An analysis was made of the risks and opportunities that may arise. The main threats, as expected, were competition and changing user needs. The most successful opportunities for us are the failures of competitors and the high cost of analogues. Also a good opportunity for growth is the general "uplift" of the market.

There is non-price competition on the market, there are several competing firms, but all of them cover only a certain part of the functionality of our system, so entering it will require some effort and investment. However, the project is quite competitive due to its high quality and the possibility of functional modification. Its low cost is due to the fact that the filtering is completely software, the development of the project does not require the cost of various materials and equipment necessary for the manufacture of the case, circuits, and the like.

Taking into account the analysis carried out, we can clearly say that further implementation of the project is advisable, because it can find its target audience and take a place in the market.

7 OCCUPATIONAL HEALTH AND SAFETY IN EMERGENCY SITUATIONS

7.1 Analysis of potential hazards

The subject of the master's project is " Investigation of baseline wander removal approaches in the electrocardiogram recordings", therefore, we will consider the workplace of a design engineer.

According to GOST 12.0.003-74 "Occupational safety standards system" [19], there are such dangerous physical and harmful production factors as:

- low or high air temperature;
- high or low air humidity;
- lack of natural light;
- insufficient illumination of the working area;
- reduced contrast.

Dangerous psychological and harmful production factors by the nature of the action are divided into:

- physical overload;
- neuropsychological overload.

For high-performance work of engineering and technical personnel in the manufacturing process of the designed filters provided for the following set of measures, excludes physically dangerous and harmful production factors.

When developing design documentation for engineers who is working on personal computer, the following dangerous and harmful factors constantly or periodically act:

- air pollution with harmful substances, dust;
- inconsistency with the norms of microclimate parameters;
- the appearance of static charges on the monitor screen, which make dust particles move to the nearest grounded object, often it is the operator's person;
- increased noise level at the workplace;

- a wide range of radiation from the display;
- increased level of electromagnetic radiation;
- increased level of ionizing radiation (soft X-ray, gamma radiation)
- lack or lack of natural light;
- insufficient illumination of the working area;
- increased brightness of light;
- reduced contrast;
- increased pulsation of the luminous flux (flickering)
- prolonged stay in the same position, and repetition of the same movements leads to the syndrome of prolonged static loads;
- inconsistency of the ergonomic characteristics of the equipment with the standardized values;
- mental overstrain, due to the nature of the tasks being solved , leads to the syndrome of prolonged psychological stress;
- a large amount of processed information, leads to significant loads on the organs of vision;
- monotony of work;
- neuropsychic stress;
- neuro-emotional stress loads;
- risk of fire.

Let’s take closer look to the insufficient illumination of the working area of the room where the personal computers are installed, as well as on the effect of increased light brightness, decreased contrast and increased pulsation of the light flux.

While user working on a personal computer, the user's eyes can withstand a heavy load and the nature of the work is constantly intense. This leads to disruption of the functional state of the visual analyzer and the central nervous system.

The reasons for the violation of the functional state of the visual analyzer are:

- constant readaptation of the organs of vision in the presence of a background of different brightness in the field of view

- insufficient clarity and contrast of the image on the screen;
- constant flickering of brightness;
- the presence of bright spots on the keyboard and screen due to the reflection of light;
- a big difference between the brightness of the working surface and the brightness of the surrounding objects;
- the presence of equidistant objects;
- low quality of initial information on paper;
- uneven and insufficient illumination at the workplace.

It is also known that noise adversely affects the auditory analyzer and other organs and systems of the human body. Of decisive importance for such action is the intensity of the noise, its frequency composition, the duration of daily exposure, the individual characteristics of a person, as well as the specifics of production activities. Activities that combine intense mental work and heavy equipment use are significantly affected by even low levels of noise. This influence is expressed in a decrease in mental performance, rapid fatigue, weakening of attention, the appearance of a headache, etc.

7.2 Measures to ensure electrical safety

Electrical safety is a system for preserving the life and health of workers in the course of labor activity associated with exposure to electric current and electromagnetic fields [29]. Electrical safety includes legal, socio-economic, organizational and technical, sanitary and hygienic, treatment and prophylactic, rehabilitation and other measures. Electrical safety rules are regulated by legal and technical documents, regulatory and technical base. Knowledge of the basics of electrical safety is mandatory for personnel servicing electrical installations and electrical equipment.

The main measures of protection against electric shock are:

- ensuring the inaccessibility of live parts under voltage for accidental contact;

- electrical separation of the network;

- elimination of the danger of injury when voltage appears on the housings, casings and other parts of electrical equipment and it is achieved by protective grounding, neutralization, protective shutdown;

- low voltages use;

- protection against accidental contact with live parts using casings, fences, double insulation;

- protection against danger in case of voltage transition from the higher side to the lower one;

- control and prevention of damage to insulation;

- compensation of the capacitive component of the earth fault current;

- the use of special electrical protective equipment - portable devices and safety devices;

- organization of safe operation of electrical installations.

To ensure the safety of work in existing electrical installations, the following organizational measures should be performed:

- appointment of persons responsible for organizing and conducting works;

- registration of a work order;

- organization of supervision over the work;

- registration of completion of work, breaks in work, transfer to other jobs.

The technical measures that must be performed in existing electrical installations to ensure the safety of work include:

- when carrying out work with the removal of voltage in existing electrical installations or near them;

- shutdown of the installation (or part of the installation) from the power supply source;

- mechanical drives blocking of the devices that disconnect the removal of fuses, disconnect the ends of the line, electricity and other measures to exclude accidental voltage supply to the work site;

- installation of safety signs and protective fences at conductive parts that remain energized and to which in the process of work it is possible to touch or approach an unacceptable distance;

- installation of grounding (turning on grounding knives or installing portable grounding)

- fencing of the workplace and hanging safety posters;

When working on live parts (or near them) which are energized:

- performance of work along with at least two workers using electrical protective equipment, under constant supervision, ensuring the safe location of workers, the mechanisms and devices used.

To eliminate the risk of electric shock, the device is reliably grounded to an autonomous ground loop in operation conditions in accordance with DSTU 7237:2011 "Occupational safety standards system. Electrical safety" [20] and the rules of operating conditions. The resistance does not exceed 4 ohms.

We will carry out calculations of the current passing through the human body, touched the grounded body at the moment of short circuit. With the following output data: U_f = 220V, $Z_{n*p} = 2Z_f$, $R_p = R_e$, $Z_r = 0$, R_h = 1000 Ohm.

First, we determine the current passing through the human body when the wires are re-grounded according to the formula 7.1

$$I_h = \frac{U_f}{3R_h} \tag{7.1}$$

$$I_h = \frac{220}{3 * 1000} = 0{,}073\ (A) = 73(mA)$$

Let's calculate the permissible protection response time. In safety conditions, there should be no more than the value determined by the expression:

(7.2)

$$t_{prot.op.} = \frac{50}{I_h}$$

$$t_{prot.op.} = \frac{50}{73} = 0{,}68(s)$$

For comparison, we determine the value of the current that passes through the human body in the absence of re-grounding ($R_{rg} = 0$)

$$I_h = \frac{2U_f}{3R_h} \quad (7.3)$$

$$I_h = \frac{2 * 220}{3 * 1000} = 0{,}146(A) = 146(mA)$$

In order to guarantee safety in this case, the maximum allowable protection operation time should be half as much, that is:

$$t_{prot.op.} = \frac{50}{146} = 0{,}34(s)$$

7.3 Measures to ensure industrial sanitation and occupational hygiene

For the normal operation of machines of electronic and computer technology and high-performance labor of workers and engineering personnel in the design process of the filters, the following set of measures is provided:

- improvement of the air environment;
- the use of optimal lighting;
- creation of optimal working conditions at the workplace;
- decrease in psycho-emotional and physical stress.

General sanitary and hygienic requirements for the air in the room in which the design bureau is located meets the requirements of GOST 12.1.005 - 88 [21]. The room is equipped with an air conditioning system, and ventilation is regularly carried out. The room is regularly wet cleaned.

According to building codes and regulations – SNiP II - 4 - 79, a mixed type of lighting is used in the room, corresponding to the II-III category of visual work. As an artificial light source, fluorescent lamps were used, which, together with the lamps, were mounted in the ceiling. In the daytime, natural lighting is mainly used, provided by the presence of windows. If necessary (protection from direct sunlight), the windows are closed with blinds. In the evening, or in cloudy weather, the staff turns on artificial lighting.

Correct organization of the workplace - the creation of the necessary conditions at the workplace for productive work and performance of work (operation) of high quality with the fullest use of equipment, waste of the employee's physical and emotional energy, increasing the content and attractiveness of work, maintaining the health of workers.

When placing the equipment, maintain the required dimensions of the gaps between the equipment, the distances from the walls, which should ensure the freedom of movement of people, the convenience of work and safety of workers; workplaces of personal computer operators, as well as areas for the preparation of technical data carriers should have a row in their location; the location of the seats can be two-row, three-row, four-row; the arrangement of the rows can be straight and transverse.

The organization of each workp

lace has its own specific features, which depend on the nature of the work performed, the qualifications of the employee, etc. From the point of view of the specifics of the machine, the workplace is organized using rational methods of working and operating the machine with the least number movements of operator and convenient observation of the processed material.

The organization of work at the enterprise is influenced by the design and parameters of the main and auxiliary equipment, must comply with the requirements of ergonomics: optimal distribution of functions in the man-machine system; responsibility of the equipment design anthropometric psychophysiological data of the working organism; observing the permissible indicators of the productive environment and sanitary and hygienic working conditions, as well as the safety of operational equipment.

The design of the working table should ensure optimal placement on the working surface (equipment) with the calculation of its number and design features of the nature of the work performed.

The height of the working surface of the table should be adjusted within 680-800 mm; in the absence of such a possibility, the height of the working surface of the table should be 725 mm. The modular dimensions of the working surface of the printer table, the structural dimensions are calculated, should be considered: width 800, 1000, 1200, 1400 mm, depth 800 and 1000 mm with its unregulated height equal to 725 mm.

The work table must have a footrest that is at least 450 mm high and at least 650 mm at the level of the extended legs.

The design of the desktop should support a rational working posture when working with the printer, allow you to change the posture in order to reduce the statistical tension of the muscles of the neck-shoulder and back to prevent fatigue.

The working chair must be lifting and swiveling and adjustable in height and angles. Seat and backrest slopes, as well as distance from the front edge of the seat.

The design of the chair should ensure maximum work results. This can be achieved only by mastering the rational methods and techniques of work in the workplace. Only they allow you to perform a given work efficiently, in the shortest time possible and without unnecessary stress.

The specifics of the work of such workers counts in high visual loads, along with low activity, monotony of the operations performed and a forced working posture. These factors negatively affect the well-being of the worker.

It was found that by rationalizing techniques and movements in the workplace, labor intensity can be reduced by 10-15%, and labor efficiency in general increases.

When organizing a workplace, a very important factor is the worker's working posture, that is, the position of his body, head, arms and legs in relation to the tools. If the worker works in a seated position, he needs to ensure a correct and comfortable seating position, which is achieved by a support for the back, arms, legs, a correct seat design, which contributes to an even distribution of body weight.

All material elements of the desktop are divided into items of permanent, temporary use and, taking this into account, are placed in an outstanding order in places of permanent storage, this saves labor movements and the efforts of the worker.

The workplace must be equipped with a footrest with a width of at least 300 mm, a depth of at least 400 mm, height adjustment up to 150 mm and an angle of inclination of the support surface of the support up to 200. The support must have a grooved surface and have a front edge side 10 mm high.

It is better to place the computer keyboard at a distance of 10-15 mm from the edge of the table, then the wrists will rest on the table. It is advisable to purchase a special wrist rest to help avoid hand disease.

For effective use of a manipulator of the "mouse" type, a special "rug" is required – a pad. Pad – the tablet must meet the basic criteria: it adheres well to the table surface

and does not burden the mouse movement.

Text input from the keyboard is facilitated by document stands. They can either be attached, for example, to a monitor, or mounted directly on a table. Many coasters are equipped with rulers for highlighting the line being typed.

Tools, equipment and objects of labor should be located at a distance of 560-750 mm at the level of the worker's hands, then their use will not lead to unnecessary movable inclinations. Important element of the rational planning of the workplace is taking into account the individual anthropometric psychophysiological data of the worker.

Workplaces are equipped with appropriate furniture and equipment that meet the most comfortable working conditions and require physiology, psychology and aesthetics.

7.4 Fire safety measures

Fires at the enterprise pose a particular danger, as they are associated with material losses. Ensuring fire safety is an integral part of government activities to protect the life and health of people, national wealth and the environment [21].

The most common causes of fires are the following:

- violation of regime requirements;
- careless handling of fire;
- violation of technological instructions;
- spontaneous combustion and self-ignition;
- discharges of static and atmospheric electricity;
- malfunction and improper operation of the equipment.

All employees, when hiring, annually at the place of work are instructed on fire safety issues.

One of the important measures for fire safety is the installation of a fire alarm in

the room. It makes it possible to quickly extinguish the fire source. The room is equipped with beam electric fire alarm (EPS) systems of the TOL (alarming, optical, beam) 10/100 type for 10-100 beams. Heat and smoke detectors of KD-1 type are used as detectors.

If smoke or smell of burnt insulation is detected, immediately disconnect the supply voltage and take measures to identify and eliminate the causes and consequences of malfunctions.

The building in which smoke exhaust valve site is located belongs to category "D" and complies with SNiP II-2-80 "Fire safety standards for the design of buildings and structures". Fire class A, E; The degree of fire resistance is not lower than III.

When designing new and renovating buildings, it is necessary to observe fire prevention measures (SNiP 2.02.02 - 85 "Fire safety standards for the design of buildings and structures.").

For extinguishing fires in the room, there are two carbon dioxide fire extinguishers of the VVK-3.5 type. This type of fire extinguisher is recommended for extinguishing fires in an enclosed space, with a small size of the combustion center, for extinguishing electrical installations.

7.5 Safety measures in emergency situations

Evacuation is carried out at the state, regional, local or facility level. Depending on the specifics of the emergency, various types of evacuation are established:

- required;
- general or partial;
- temporary or irrevocable.

The decision to carry out the evacuation is made by:

- at the state level - the Cabinet of Ministers of Ukraine;
- at the regional level - regional state administrations;
- at the local level - district state administrations and local governments;
- at the facility level - facility managers.

In the event of radiation accidents, the decision to evacuate the population is made by local state administrations on the basis of the conclusion of the Sanitary and Epidemiological Service on the predicted exposure dose to the population or on the basis of information received from the heads of radiation hazardous facilities. [22]

In urgent cases decision to conduct an emergency evacuation of the population can be made by the head of the emergency response, and in his absence, the head of any emergency rescue service, was the first to arrive in the emergency zone.

Mandatory evacuation of the population is carried out in cases of the following threats:

- accidents with the release of radioactive or hazardous chemicals;
- catastrophic flooding of the area;
- massive forest and peat fires, earthquakes, landslides, as well as other geological and hydrogeological phenomena and processes;
- armed conflicts (from areas of possible military operations to safe areas determined by the Ministry of Defense of Ukraine for a special period).

General evacuation is carried out for all categories of the population from the zones:

- possible radioactive and chemical contamination;
- catastrophic flooding of the area, for which the time of arrival of the breakthrough wave is 4:00 before the destruction of the hydraulic structure.

Partial evacuation is carried out for the removal of categories of the population who, due to age or health reasons, cannot evacuate on their own, as well as persons who officially take care of them.

Evacuation is provided by:

- creation of regional, local and facility evacuation bodies;
- planning of evacuation;
- determination of safe areas suitable for accommodating the evacuated population and property;
- organization of notification of facility managers and the population about the beginning of the evacuation;
- organization of evacuation management;
- life support of the evacuated population in places of their safe accommodation;
- training the population in actions during evacuation.

For the removal of the bulk of the population from the emergency zone or areas of possible hostilities, vehicles of facilities are involved, and in the event of an immediate threat to the life or health of the population – all available vehicles of facilities and citizens.

Objects and citizens whose vehicles are suitable for evacuation are compensated for the cost of providing services and the actual costs of funds allocated to eliminate the consequences of an emergency or eliminate the threat of its occurrence.

Facility workers, owners, users, vehicle drivers who have refused to provide public transportation services due to an emergency are in compliance with the law.

The evacuation of Ukrainian citizens who are on the territory of foreign states, in the event of a threat to their life or health, is carried out by the State Emergency Service of Ukraine.

The evacuation of material and cultural values is carried out only if there is time for it.

In cities and other settlements where there are high-security facilities, with incomplete provision of protective structures, the main way to protect the population is to evacuate and place it in areas that are safe for people and animals.

The population living in settlements located in areas of possible catastrophic flooding, dangerous radioactive contamination, chemical damage, natural disasters, accidents and disasters is subject to evacuation.

Taking into account the situation that developed at the time of the emergency, a general or partial evacuation of the population of a temporary or irreversible nature can be carried out.

General evacuation is carried out by the decision of the Cabinet of Ministers of Ukraine for all categories of the population and is planned in the event of: possible dangerous radioactive contamination of territories (with a threat to the life and health of people); the emergence of the threat of catastrophic flooding.

Partial evacuation is carried out by decision of the Cabinet of Ministers of Ukraine in the event of a threat or an emergency.

Evacuation measures are carried out by the Council of Ministers of the Autonomous Republic of Crimea, local executive authorities, and local self-government bodies.

When a partial evacuation is carried out, the unemployed in the production and service of the population is removed in advance; children, students of educational institutions, inmates of orphanages, together with teachers and educators, students, pensioners and disabled people "who are in nursing homes, together with service personnel and their families.

Evacuation of the population is planned in the event of: an accident at a nuclear power plant with possible radioactive contamination of the territory; all types of accidents with the release of potent toxic substances, the threat of flooding the area, forest peat fires, earthquakes, landslides and other geophysical hydrometeorological phenomena with severe consequences. In wartime - from the damaging factors of weapons of mass destruction, conventional weapons.

In order to carry out an organized evacuation, to prevent panic and loss of life, it is necessary: to plan the evacuation of the population in advance; identify areas suitable for accommodating evacuees from hazardous areas; organize notification of the heads of enterprises and the population about the beginning of the evacuation; organize evacuation management, worry about life support in places where the evacuated population is located; organize training for children during the evacuation.

Evacuation is the orderly withdrawal or removal of people from objects and settlements, staying in which becomes life-threatening. The main purpose of the evacuation is to ensure the safety of every person and everyone. Valuables, documentation and archival materials are subject to evacuation.

CONCLUSIONS AND FUTURE WORK

The examination of the ECG has been comprehensively used for diagnosing heart diseases. Various techniques have been proposed earlier in the literature for reduction of baseline wander interference from ECG. This paper provides an overview of various filtration techniques available in the literature for removal of Baseline Wander interference. Literature indicates that the filtration techniques for ECG must be highly accurate and should ensure fast filtration. In the present paper effort has been made to perform the comparative analysis of different filters that were proposed earlier by various authors for suppression of base line wander interference.

The ECG signal is corrupted by different types of noises as a high frequency noise and low frequency noise. The algorithms which are used in this project can improve the performance of filtering for these types of signals. As a conclusion, baseline wander removal is a filtering need which can be implemented efficiently in an embedded platform. In this project, we have developed several implementations for baseline wander removal and the results of posterior delineation show that it helps to process the ECG signal in noisy contexts in an embedded platform.

In this project FIR and IIR filters were used to remove the low frequency noise. The output of the FIR filter is very near about the desired value and has small removal of low frequency noise while the output which we get through IIR filter has less value than the desired output. Another important conclusion which we get through the observation is this that the standard deviation of IIR filter is much closer to the desired output & the standard deviation of the FIR filter output with high frequency noise have less value than the IIR filter. The results which are given by FIR filter for proposed algorithm have much accurate results compared with IIR filter.

For future work, it would be needed to use another source of ECG signal instead of the Physionet database. We have validated the implementations by using a program to send the node the input samples whereas this project stands for realtime ECG processing in a wearable platform. It has been proved that implementations here presented are acceptable to run in an embedded platform, so the next step may have been to perform a real ECG ambulatory processing by the use of a node. Also future work may concentrate on designing of filters for accurate and fast filtration of ECG which ultimately results in the improvement of accuracy during diagnosing the cardiac disease at the earliest in the use of patient monitoring systems.

Regarding the implementation of a Wireless Body Sensor Network, these implementations would be only the step in a more complex system but, at the same time, a filtering stage is needed for posterior processing. Because of the optimizations made, the morphological filtering implementation offers a good performance to support posterior operations.

According to the results of noise suppression is needed. As exposed in the first chapter, noise suppression is a major challenge in ECG processing and there is not a suitable method yet. Approach to noise suppression may result in a better performance.

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