Rafał KOTAS[1], Marek KAMIŃSKI[1], Piotr MAZUR[1], Jakub CHŁAPIŃSKI[1], Bartosz SAKOWICZ[1], Andrzej NAPIERALSKI[1], Małgorzata KURPESA[2]

Lodz University of Technology, Department of Microelectronics and Computer Science (1), Medical University of Lodz, Department of Cardiology, Lodz, Poland (2)

Project of open-source software platform for sudden cardiac death (SCD) risk stratification and advanced ECG analysis

Streszczenie. *Artykuł prezentuje główny cel projektu, którym jest opracowanie otwartej platformy do stratyfikacji ryzyka nagłego zgonu sercowego w oparciu o przebiegi EKG z zapisów holterowskich na postawie znanych i zweryfikowanych klinicznie wskaźników: mikrowoltowej naprzemienności załamka T, turbulencji rytmu serca, zmienności rytmu zatokowego i współczynnika akceleracji/deceleracji rytmu serca. (**Projekt otwartej platformy do stratyfikacji ryzyka nagłego zgonu sercowego w oparciu o zaawansowaną analizę przebiegów EKG.**)*

Abstract*. This paper presents the main goal of the "Sudden Cardiac Death risk stratification based on functional assessment of autonomic nervous system with the use of Holter methods" project, which is development of unified, generally available, extendable, open-source software platform for ECG signal analysis from numerous types of Holter recorders, allowing for high-risk markers assessment. Realization of this project would greatly simplify selection of high-risk patients.*

Słowa kluczowe: EKG, Holter, Nagły Zgon Sercowy, Alternans Załamka T.
Keywords: ECG, Holter, Sudden Cardiac Death. T-Wave Alternans.

Introduction

Sudden Cardiac Death - SCD is a death from causes attributable to the heart, preceded by a sudden loss of consciousness, which takes place shortly (less than one hour) after appearance of acute symptoms in patients with heart disease. Sudden Cardiac Death (SCD) is currently a considerable social issue. It is estimated that 30 out of 1 million of population die from SCD every week. In Poland, 1200 SCD related deaths are being classified every week. This group accounts for 50% of all deaths caused by cardiovascular system illnesses (Figure 1). According to numerous sources 10 to 32 percent of all natural deaths are sudden deaths, and about 80 to 90 percent of all sudden deaths are classified as SCDs [1, 2].

Clinical conditions that increase the risk of SCD can be found in broad population of patients, therefore to identify highest risk cases it is often necessary to perform a number of clinical tests, such as: coronary perfusion assessment (exercise test, changes of ST segment, angiography), heart failure assessment (NYHA class, ejection fraction, exercise time), autonomic nervous system assessment (heart rate variability, baroreceptors sensitivity) and cardiac dysrhytmia assessment (ambulatory ECG recording, mean ECG, QT segment analysis, exercise test, electrophysiological test). As a result of limited possibility of high-risk patients' identification, high SCD prevention efficiency of implantable cardioverter defibrillator does not influence directly the overall number of SCDs.

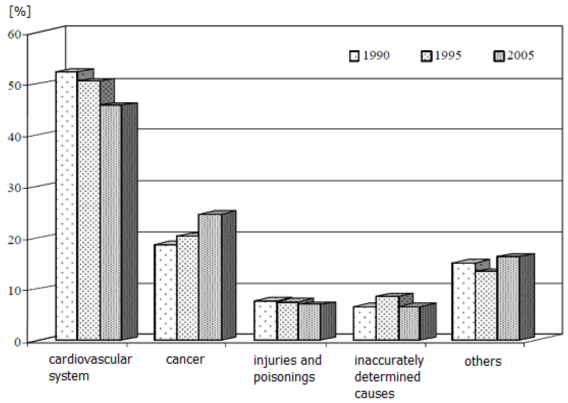

Fig.1 Causes of death statistics

Recently several markers based on ECG Signal were developed that pose high prediction value for SCD [3]. Among these markers are T-wave alternans (TWA), heart rate variability (HRV), heart rate turbulence (HRT) and deceleration capacity (DC).

A number of other parameter analyses will be implemented in a future stage of described project. Every single analysis will be designed as an independent plug-in. Use of additional software package for ECG analysis of all patients imposes only minimal cost in clinical practice, and it can be emplyed along with currently used diagnostic software. In addition, modular structure of the software and its source code availability will simplify the task of development and introduction of new algorithms for ECG analysis.

The article is divided into three main sections, first of which deals with the state of the art in field of SCD risk stratification. The second section presents the structure of the designed software platform, while third describes the technology used in the project.

State of the art

For SCD risk stratification authors will use a set of four markers based on ECG signal: TWA, HRT, HRV and DC/AC.

Previous clinical study shows comparable prediction value of TWA and electrophysiology study (EPS) in prognosis of cardiac events caused by ventricular arrhythmia. Positive TWA assessment successfully identifies a high-risk patient with high probability of dangerous ventricular arrhythmia and SCD occurrence. TWA assessment has also a high negative prognostic value comparable with EPS. The advantage of TWA over EPS is its noninvasiveness [4].

During 20-month observation it was shown [5], that cardiac events (SCD, cardiac arrest, ICD discharge) occurred in 81% of patients population with positive MTWA results and only in 6% patients with negative MTWA results. Similar results were also presented in different studies [6, 7, 8].

Heart rate turbulence (HRT) is a physiological, two-phase response of sinoatrial node to premature ventricular contraction (PVC). This response consists of short heart rate acceleration phase, after which the heart rate slows to a normal pace. To assess HRT two separate parameters are used:

- turbulence onset (TO), defined as percentage ratio of heart rate before PVC to the heart rate right after PVC. Calculation of TO parameter:

(1) $$TO = \frac{(RR_1 + RR_2) - (RR_{-2} + RR_{-1})}{(RR_{-2} + RR_{-1})} \cdot 100\%$$

where: TO - turbulence onset,RR_i – length of QRS complex (Figure 2).

- turbulence slope (TS) which is defined as the most steep regression line trough each 5 consecutive distances in normal sinusoidal rhythm in ECG. Calculation of TS parameter:

(2) $$a_i = \frac{2 \cdot RR_{i+4} + RR_{i+3} - RR_{i+1} - 2 \cdot RR_i}{10}$$
$$TS = \max(a_i)$$
$$i \in \langle 1,16 \rangle$$

where: TS – turbulence slope, RR_i – length of QRS complex.

In order to correctly assess HRT one needs to make sure that the turbulence onset event was in fact a PVC (and not for instance a T-wave) and also that the sinus rhythm after PVC event is free from artifacts, distortions and improperly classified heartbeats. HRT, independently from other risk factors, has the best prediction value among all ECG prognostic markers [9]. This prediction value is comparable to the result of ejection fraction of left ventricle.

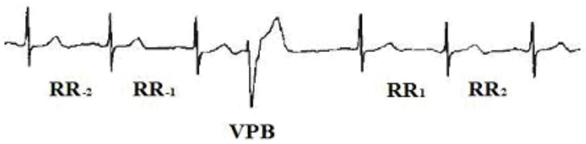

Fig.2 HRT parameter calculation (VPB - ventricular premature beat)

Heart rate variability (HRV) defines short-term time differences in duration of consecutive RR distances in sinusoidal rhythm registered in ECG signal. The most acknowledged parameter is standard deviation of all normal RR intervals (SDNN), which value below 50 ms is considered abnormal [10]. It was verified in numerous publications that lowered HRV is an independent risk factor in patients with myocardial infarction.

During Deceleration capacity (DC) and corresponding acceleration capacity (AC) provide a quantitative assessment of heart rhythm capacity to decelerate and accelerate respectively. Parameter values are calculated using phase-rectified signal averaging (PRSA) method, after synchronization of all periodic oscillations of RR intervals excluding all non-periodic distortions (artifacts, noise, etc.) (Figure 3). Calculation of DC parameter:

(3) $$DC = \frac{\sum_{i}^{Y-Y_{i-1i}} (Y_i + Y_{i+1} - Y_{i-1} - Y_{i-2})}{4 l_{DC}}$$

where: Y_i – heartbeat interwal [ms]; l_{DC} – number of beats where Y_i<Y_{i-1}.

In clinical practice only DC parameter is used, as it has a greater prediction ability of death after myocardial infarction in comparison to lowered ejection fraction of left ventricle (EF) or conventional HRV markers (SDNN) [11].

Described markers are used to assess the risk of occurrence of life-threatening cardiac events. Based on their values a risk stratification models are designed, usually consisting of threshold values for parameters above (or below) which the risk is greater. For example turbulence slope (TS) below 2.5 ms or deceleration capacity (DC) below 3.5 ms indicate a high risk. Model efficacy is assessed basing mostly on: positive predictive accuracy (PPA), negative predictive accuracy (NPA), sensitivity, specificity; calculated for control group of patients.

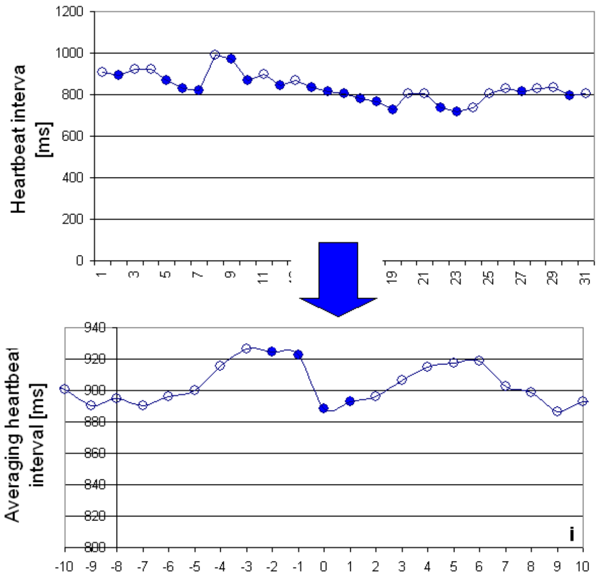

Fig.3 Generation of PRSA function of DC parameter

It should be noted that currently used models are relatively simple (based on one or at most two indices), and their parameters are chosen arbitrarily by the medical staff. Predictive model of opportunities depend mainly on the size of the control group. [12] describes a study based on a group of 2343 patients and [13] on a group of 1200 patients. Similar studies conducted in Poland consisted of a much smaller patient base. Even in a single medical facility often different, incompatible Holter systems are used, not allowing for a full set of analyses to be performed. Therefore it is very difficult to obtain a large group of patients to provide statistically reliable results. Realization of described project will provide means to obtain much larger control groups for research in Poland. Important innovation in comparison with current methodology will be an automatic risk stratification model design through optimization algorithms. This will allow for a significant increase of complexity level in these models (parameters depending on age, sex, or other risk factors).

The functional structure of the platform

Software platform will be implemented with the use of Java technology, which will allow using is in any popular operating system. Platform functionality will be divided into following modules:

Patient database

- registration of results from numerous medical examinations and tests (ie.: blood pressure, complete blood count etc.);
- registration and visualization of patients condition history;
- patients and results search according to various criteria.

Signal acquisition

- importing Holter recordings from various file formats.

The main feature of described platform will be the ability to analyze a wide range of different file formats used by different Holter systems and recorders. As a result, the platform would not impose any limitation on digital ECG signal resolution, sampling frequency and number of channels. During segmentation and analysis phase the software will allow for automatic detection of best quality channel as well as parallel analysis of multiple channels at the same time. New data formats will be introduced through a plug-in infrastructure.

Initial preprocessing

- ECG signal filtering with the use of FIR and IIR filters (including zero-phase approach);
- Baseline wandering removal with both spectral and time-domain (curve subtraction) methods;

ECG signal segmentation and analysis

- heartbeat separation and segment identification;
- artifact and arrhythmia detection;
- template based heartbeat classification;
- HRT, HRV, DC (AC) and TWA (with MMA and spectral methods) assessment.

The key algorithm in ECG segmentation consists of QRS complex detection. Numerous methods are presently known that allow for QRS complex detection [14, 15], and further studies into this matter are being conducted.

Statistical module

- generation of reports and statements for a given group of patients;
- statistical analysis of marker dynamics in accordance to various criteria like age, sex, profession, weight, time of day, etc.

Model generation module

- model extraction based on optimization of: positive predictive accuracy, negative predictive accuracy, sensitivity, specificity. It will also be possible to extract the model basing on different preconditions (age groups, sex, etc.).

Plug-in architecture

In the described project software architecture will be designed in a modular manner, allowing to extend the platforms functionality with plug-in software without the necessity of rebuilding and modifying the main source code. As a result the platform will be a very convenient tool for performing a complex research and testing of various algorithms for ECG analysis.

Authors decided to use a modular structure of designed platform. This kind of structure of software along with source code availability will simplify the task of research and introduction of new algorithms for ECG analysis. The software will be extensible allowing for further improvement and extensions of its features. Moreover designed software will be patent and royalty free, generally available along with its source code, which could significantly accelerate the research on ECG analysis worldwide.

A plug-in is a set of software components that adds specific abilities to a software application (Figure 4). If supported, plug-ins enable customizing of the functionality in an application. For example, plug-ins are commonly used in web browsers to play video, scan for viruses, and display new file types.

A software framework is an abstraction in which software providing generic functionality can be selectively changed by user code, thus providing application specific software. A software framework is a universal, reusable software platform used to develop applications, products and solutions. Software Frameworks include support programs, compilers, code libraries, application programming interfaces (APIs) and tool sets that bring together all the different components to enable development of a project or solution. To achieve goals of the project authors considered many popular and well known frameworks.

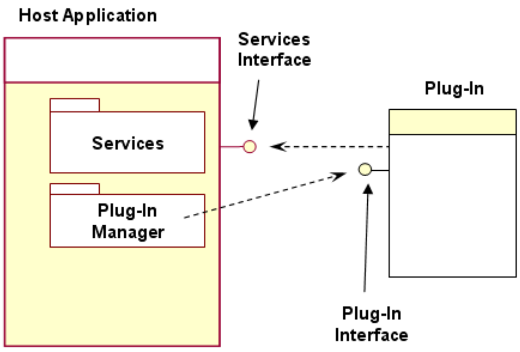

Fig.4 The example plug-in framework

The examples of the frameworks, which could be used in the development of designed software platform:

- OSGi (Open Services Gateway initiative) Service Platform;
- Java Plug-in Framework;
- NetBeans Platform.

OSGi service platform

OSGi is a set of specifications that define a dynamic component system for Java programming language[16]. These specifications enable a development model where applications are (dynamically) composed of many different (reusable) components. The OSGi specifications enable components to hide their implementations from other components while communicating through services, which are objects that are specifically shared between components. This surprisingly simple model has far reaching effects for almost any aspect of the software development process.

OSGi offers reusable services common to desktop applications, allowing developers to focus on the logic specific to their application. Among the advantages of the platform are: highly configurable, easy to expand, user-friendly tool for project design.

Java plug-in framework

Java Plug-in Framework project is the open source, LGPL licensed plug-in infrastructure library for new or existing Java projects. JPF provides a runtime engine that dynamically discovers and loads "plug-ins". A plug-in is a structured component that describes itself to JPF using a "manifest" file. JPF maintains a registry of available plug-ins and the functions they provide (via extension points and extensions) [17].

One major goal of JPF is that the application (and its end-user) should not pay any memory or performance penalty for plug-ins that are installed, but not used. Plug-ins are added to the registry at application start-up or while the application is running but they are not loaded until they are called.

The main advantages of this framework is the implementation of: built-in integrity check, plug-ins self-documentation, plug-in dependency check, lazy plug-in activation and "on the fly" plug-in registration and activation. Despite all of these features JPF is not popular and not supported by the community.

Netbeans Platform

The NetBeans Platform is a broad set of Java frameworks and tools which allow for building complex desktop applications. NetBeans IDE itself is one of the hundreds of applications based on the NetBeans Platform. The NetBeans Platform contains APIs that simplify the handling of windows, actions, files, and many other aspects of typical applications [18].

Each distinct feature in a NetBeans Platform application can be provided by a distinct NetBeans module, which is comparable to a plugin. A NetBeans module is a group of Java classes that provides an application with a specific feature.

Summary

Expected project results:
- Clinical diagnostic procedure of SCD risk stratification based on Holter ECG monitoring;
- Open and generally available software platform for ECG signal analysis and patients management with statistical reporting facilities. Software will be extensible trough plug-in architecture to further improve and extend its features. Software will be patent and royalty free, generally available together with the source code, which could significantly accelerate the research on ECG analysis
- Algorithms for ECG signal processing, especially segmentation and segments identification adjusted for data from Holter recorders.

Currently the OSGi specification is being considered as most suitable for developing the software platform.

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***Autorzy**: mgr inż. Rafał Kotas, E-mail: rkotas@dmcs.pl, dr inż. Marek Kamiński, E-mail: kamiński@dmcs.pl, mgr inż. Piotr Mazur, E-mail: pmazur@dmcs.pl, dr inż. Jakub Chłapiński, E-mail: jchlapi@dmcs.pl, dr inż. Bartosz Sakowicz, E-mail: sakowicz@dmcs.pl, prof. dr hab. Inż. Andrzej Napieralski, E-mail: napier@dmcs.pl Politechnika Łódzka, Katedra Mikroelektroniki i Technik Informatycznych, ul. Wólczańska 221/223, 90-924 Łódź; prof. dr hab. n. med. Małgorzata Kurpesa, Uniwersytet Medyczny w Łodzi, Klinika Kardiologii, ul. Kniaziewicza 1/5, 91-347 Łódź, E-mail: malgorzata.kurpesa@umed.lodz.pl.*