eLab: A Web-based Platform to Perform HRV and HRT Analysis and Store Cardiac Signals

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Abstract

This study aimed to develop a user-friendly, modular and scalable web-based system, that would allow researchers and physicians to upload and save cardiac signals into a custom database, and would perform a complete heart rate variability (HRV) and heart rate turbulence (HRT) analysis of each anonymous RR-interval time series from holter records. The built system, called eLab, complies with the previous requirements. The HRV and HRT analysis results are stored and can be presented to users using plots and tabular information or downloaded. Users only need a web-browser to use this tool.

The main components of eLab are the following. (1) A database of ECG and RR-interval time series. To allow efficient access to signal data, series are divided into several time interval segments following an AVL tree. (2) A HRV and a HRT signal analysis toolboxes. All indices computed are stored in the database. (3) A user-friendly Web Interface.

The components of eLab are communicated by means of client-server connections through an ICE (Internet Communications Engine) interface. ICE provides complete independence from any programming language or platform and its great efficiency in terms of bandwidth load. The design of eLab as isolated modules interconnected using ICE interface allows to replace or add new modules in an efficient way, without affecting the interoperability of the system.

1. Introduction

Clinical diagnoses and basic investigations are critically dependent on the ability to record and analyse physiological signals. This works aims to develop an application to provide researchers and clinicians with a toolset that would allow them to analyse easily, quickly and accurately physiological signals.

The present work is focused on ambulatory ECG signals (Holter) analysis to obtain non-invasive cardiovascular risk markers of arrhythmic Sudden Cardiac Death (SCD), which is the cause of 1 million deaths every year [1].

Multiple risk factors could be measured and reported simultaneously giving the clinician a comprehensive view of the cardiovascular risk. Those based on ECG signal analysis had provided interesting results in terms of feasibility, clinical results and predictive value [2, 3]. Among them, autonomic markers, namely, Heart Rate Variability (HRV) and Heart Rate Turbulence (HRT), and ventricular repolarization marker T-Wave Alternans (TWA), have been widely studied in the literature in recent years [4–6].

However, the use of HRV and HRT in clinical practice to guide clinical decisions or risk assessment for SCD is limited, if not absent. Indeed, HRT and HRV standards [3, 5] do not recommend a routine use in clinical practice so far. This could be due to three main factors [7]; (1) The need for big, randomized clinical studies to gain more precise insight into the pathophysiological link between HRV/HRT and mortality/morbidity; (2) The need for complete validation of the robustness and limitations of the algorithms; (3) The need to a deeper understanding of the background of the methods by the end-user (clinicians), to avoid the used of these methods as *black-boxes*.

There are several initiatives that allows the research community to perform signal analysis on Holter recordings, e.g., PhysioNet [8], HRV-site (R-HRV) [9] and libRASCH [10], but they are research-oriented. However, all the approaches presented are clearly research-oriented, and they often require a deep knowledge of programming skills (C, and R) and a deep knowledge of the mathematical background of the methods.

The aim of this work was to build a tool which would allow to manage and create a complete database of Holters and link this information with clinical data. It would also enable the complete HRV and HRT analysis. The interaction with the system is carried out using a web application,

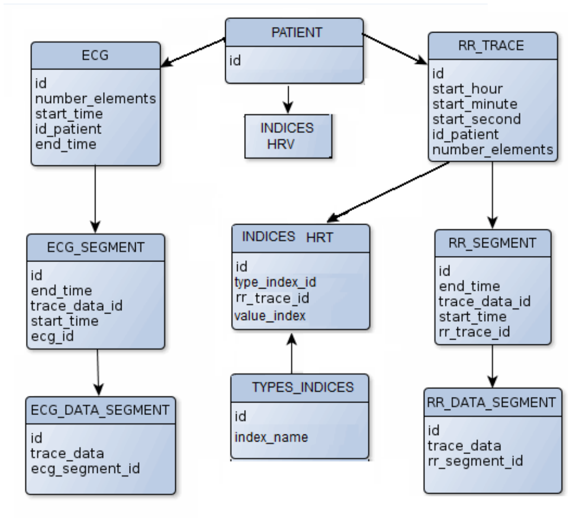


Figure 1. *eLab database schema. The main table is* PATIENT*. RR-intervals* id*, start time and* end time *are stored in* RR-TRACE *table. RR-intervals are divide into segments, whose information is stored in* RR-SEGMENT *table. The RR-intervals actual values are stored in* RR-DATA-SEGMENT*. ECG cardiac signal are stored in an analogous way. The ECG basic information is stored in* ECG*, consequently segmentation and actual real values are stored in* ECG_SEGMENT *and* ECG_DATA_SEGMENT *tables. Indices values are stored in* INDICES *table.*

which is easy to use and which has a user-friendly interface. An additional objective was to try to overcome the lack of confidence that end-users have with the methods of analysis.

The current work is based on a previous project called VPREDICT+ (`www.vpredict.org`), which aimed to create a platform for SCD prediction.It could be tested and used by physicians and engineers that belonged to VPREDICT+ consortium.

The scheme of the paper is as follows. In section 2, the main components of eLab are described in detail. In section 3, the eLab workflow and functionalities are shown using a patient example. Section4 contains the discussion of this work and future works.

2. eLab project

The problem we want to address in this work is to build a tool that: (1) allows to store and manage cardiac electrical signals in an efficient way, (2) allows to process them for HRV/HRT analysis in the context of cardiac risk assessment, and (3) provides with a user-friendly environment.

The solution we propose is a modular and scalable system, in which each module tries to solve each one of the three issues in the problem. The system aims to be flexible enough to implement each module using the technology best suited for the addressed problem. The complete system is integrated using, mainly, ICE (Internet Communications Engine) technology.

The eLab systems, which is the solution we implemented, has the following main modules:

- *Time Series Database.* This module was designed as a general database to store time series in an efficient way. In particular, it allows to store and manage ECG signals and RR-interval time series from the Holter, which are the main cardiac signals involved in this project. The database was implemented using MySQL technology following an AVL tree structure to reduce search time and to store a large amount of data (see Figure 1). The interaction with the database was established by the implementation of an API using Java Persistence API (JPA). JPA provides portability to eLab system allowing to change the database technology from MySQL to another one if needed in a new scenario.
- *Signal analysis modules.* We implemented two independent signal processing modules: (1) HRV analysis module implemented in Java, and (2) HRT analysis module implemented in Python. Both programming languages are object-oriented and allowing to create modular programs and reusable code. In addition, they are platform-independent what allows to run the same program on many different systems. So that, the different developed modules can be executed in a distributed and scalable way, what is crucial for the solution we proposed.

HRV analysis module has the following pacakges to estimate the most usual indices [5]: time-domain, frequency-domain and nonlinear indices (approximate entropy and detrended fluctuation analysis) [5, 11–13].

HRT toolbox allows to compute the Turbulence Onset (TO) and Turbulence Slope (TS) parameters that assess the sinus acceleration and subsequent deceleration of the heart rate following a ventricular premature beat [3, 4].

- *Web User interface.* This module contains the web interface with the user and the access to the complete system. It provides an output by generating web pages with the information retrieved from the eLab system transmitted via the Internet and viewed by the user using a web browser program. The requirements of the user interface were to offer functionality, ubiquity and a user-friendly interface. We developed the web application with PHP and Highcharts to plot graphics.

One of the main advantages of this approach is that there is no need to install any plug-in or other specific software. All processes related to eLab system functionalities are launched from the web interface. Figure 2 shows eLab home page, how to calculate HRT and HRV indices for a new patient and how to display the list of patients created in the database. The graphic results help the physician to get used to the meaning of some risk markers.

- *Interconnection between systems.* eLab project was

(a) New patient (b) List of patients

(c) Home page (d) TINN computation graphic

Figure 2. *How to calculate HRT and HRV indices for a new patient from web interface. How to display the list of patients created in the database. eLab home page, and a help graphic from TINN index*

built using the concept of *location transparency*, so that any module may run on a different computer. This concept plays an important role in the development of truly scalable distributed applications. We implemented *location transparency* in eLab by using only object-oriented and platform-independent programming languages (Java, Python, etc). We also used a middleware software that uses an abstract Interface Description Language (IDL) to specify possible interactions in terms of object interfaces. Figure 3 shows the complete architecture of eLab and how the different components are interconnected.

The connection among eLab components was made through ICE (Internet Communications Engine) interfaces. ICE is a modern middleware that uses Slice files as abstract specifications of the remote interactions. Each module knows all the needed Slice interfaces to interact with any other module [14]. ICE has good performance figures such as CPU workload, latency and throughput, when a great amount of data must be transmitted. One of the main characteristics of ICE, regarding eLab, is that new modules can be added, or older ones replaced in an efficient way, without affecting other modules in the system.

3. eLab workflow

The interaction with eLab begins with the welcome page (see Figure 2(c)). There are two main actions available for anonymous users, namely, to display indices stored in the database, and calculate indices for a new patient.

Calcula nuevo paciente (Compute new patient) button links to a form that accepts as input a path of a RR-interval file and a patient *id*. The file must be ASCII file, containing beat positions, measured in milliseconds, and labels with the type of beat (normal, ventricular, artifact or calibration). The eLab system begin the process by open and

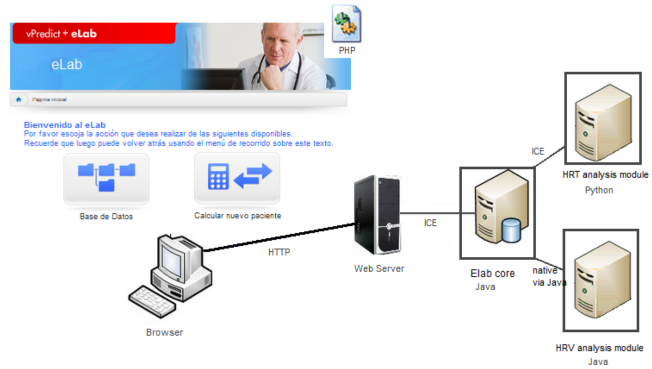
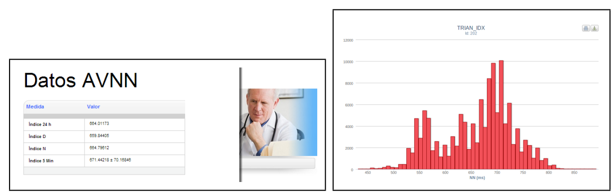


Figure 3. *Connection architecture of eLab system. eLab web page is connected via HTTP connection with Web server, which in turn is connected to eLab core through an ICE interface. HRT module is connected with eLab by another ICE interface, whereas HRV is connected by java methods directly.*



(a)AVNN index value (b)A graph of TRIAN index

Figure 4. *Some results obtained from HRV analysis.*

read the RR-intervals file, then the actual sample values are stored in the database. Afterwards, a call to compute HRV and HRT indices is automatically sent to the respective modules. HRV process might take some time due to the preprocessing step and the computation of entropy and fractal indices. eLab core communicates with the HRV module via Java calls, and with HRT module via a precompiled ICE interface. Finally, HRV and HRT indices are stored in the database.

The user may either display indices calculated or download the data for stored patients. We have integrated HRV and HRT packages in the eLab site, allowing HRV and HRT analysis to be performed via web without installing any software in local computers. Figure 4 is a composition showing some results obtained from HRV analysis. It represents two different HRV indices, namely, AVNN, and the helping graph for TRIAN index.

4. Conclusions

This paper presents eLab, a modular systems that intends to: (1) manage and store cardiac electrical signals in an efficient way, (2) process them for HRV/HRT analysis in the context of cardiac risk assessment, and (3) provide with a user-friendly environment to interact with the system.

From the architectural point of view, the eLab system was implemented to allow (1) reusability of code, (2) scalability of the system and (3) location transparency. We fulfil these caracterisitics by (1) using only open-source object-oriented programming languages, (2) building eLab system with autonomous modules, and (3) using a middleware (ICE) that allows interaction between modules in terms of objects interafces. The end-user interacts with the eLab system by a web-user interface. Therefore, different from other approaches eLab does not need to dowload and install any software.

A user can work with records from eLab database or upload their own records, select the type of analysis and obtain the results. eLab allows complete graphical interpretation for the HRV analysis method whenever possible. Even thought, avoid completely the use of these methods as black-boxes is hard to achieve, so that graphical results allows to gain better understanding of the methods. The aim is to try to overcome lack of confidence that end-users have with these methods. The long-term goal of the eLab system is to help to carry out big, randomized clinical studies to gain more precise insight into the pathophysiological link between HRV/HRT and mortality/morbidity.

So far, the main focus of eLab has been to handle ambulatory ECG signals (Holter) but the modular design of eLab would allow to handle other kind of signals such as EGMs or EEG. Scalability of eLab system would allow to add new modules of signal processing in a efficient way, without the needed of rebuild the existing ones.

As future work, we are working to integrate eLab with an EHR system, allowing to connect clinical information with data from Holter analysis.

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