gVARVI: A Graphical Software Tool for the Acquisition of the Heart Rate in Response to Visual Stimuli

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Abstract

In this paper, the gVARVI software tool is presented. It was been developed in Python, and it is aimed at recording the heart rate data signal while the user is either receiving a sequence of visual stimuli, or performing a sequence of actions, that is, an activity. Heart rata data are acquired from wireless chest straps using bluetooth or ANT+ protocols. From the graphical interface, the user can design new activities of different types: video, sounds, pictures and keyboard controlled actions. After selecting an specific activity and a device, an experiment may be ordered and the results can be stored or previewed.

In this paper all functionalities of gVARVI are described, and an example of use is also provided. Results of the usability test are also presented. This is an open source tool that can be downloaded from `http://gvarvi.milegroup.net`. At present, the tools is being used by physicians and psychiatrists for performing heart rate variability studies.

Key words: Heart Rate Variability, Visual Stimuli, Graphical User Interface

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1. Introduction

The heartbeats are originated as spontaneous electrical activity in the sino-atrial node of the heart. The heart rate is the number of heartbeats per unit of time, generally expressed as beats per minute [1], [2]. This electrical activity of the heart can be recorded onto the electrocardiogram (ECG), a noninvasive and harmless method usually employed for diagnosis and screening of cardiovascular disease (CVD) [3]. The sinus rhythm corresponds to normal, regular rhythm of the heart, and is derived from the RR intervals (distances between two consecutive beats) of the ECG, considering only normal interbeat intervals.

The heart rate is not constant; it varies to adapt to different internal and external stress factors. The heart rate variability (HRV) refers to the alterations, beat to beat, in the heart rhythm. The HRV is the result of balancing the influence between the parasympathetic system (heart rate acceleration) and the sympathetic system (heart rate deceleration) [4]. The analysis of the HRV is employed as a noninvasive measure of the status of the cardiovascular system. It can be performed employing heart rate analysis in both time domain and frequency domain, or even employing nonlinear analysis techniques.

It has already been stated that ECG is commonly used to diagnose CVD; however, cardiac monitoring systems are not limited nowadays to hospitals and health centers, where the ECG recording and/or heart rate acquisition are performed employing sophisticated and expensive medical devices. By contrary, emerging monitoring systems are currently being developed and employed in an increasing number of varied situations different from cardiac disease, such as for sleep monitoring at home [5], or for people with mental disorders, for example schizophrenia [6] or depression [7]. Several studies analyzing heart rate variables were also conducted over healthy population to characterize the cardiac stress status during physical exercise [8], or during specific squat exercise [9], or to analyze the effects of different emotional experiences over the HRV [10].

Related to these reactions to emotional stimuli, it is well known that the peripheral nervous system is responsible of different human actions that may appear as a consequence of specific external stimuli [11]. In this way, the heart rate patterns of a person should be affected by several inputs causing emotional influence. For example, his/her cardiovagal response to motion sickness and perception-based events may vary when the person is viewing specific black and white stripes [12]. Other visual experiences that have been studied in terms of emotional reactions and HRV are the viewing of political ads [13] or violence videos [14]. Results of these previous works [10]-[14] show differences in the parasympathetic nervous activity while the person is perceiving different types of stimuli.

At present, several mobile devices for real time heart rate monitoring can be found in the literature, such as HeartSaver, which allows the automatic detection of several cardiac pathologies by analyzing the corresponding ECG [15]; the smartphone-based platform developed by Oresko et al. [16]; or portable equipment for monitoring elderly at home [17], [18].

Recent developments in technology have enabled an increasing number of population to dispose of either a smartphone or mobile device, which can measure the heart rate in real time. All of them employ different applications that track the heart rate employing the camera and flash (the finger should be positioned on the camera lens, which captures the color changes that occur each time the heart beats) such as Instant Heart Rate, developed by Azumio, for both iOS and Android (www.azumio.com); Runtastic Heart Rate Pro, also for both iOS and Android (www.runtastic.com); or Cardiio, for IOS, that allows to measure the heart rate from either the finger or the face (www.cardiio.com). Other applications employ a chest strap that records the heart data, which are then transmitted to the electronic device in real time. Examples can be SportsTracker (www.sports-tracker.com) or Endomondo (www.endomondo.com).

In the last years, several watches connected to smartphones are being developed to record the heart rate employing sensors, such as the Apple Watches (www.apple.com/watch/), or the Polar Watches (www.polar.com).

As far as we know, all the existing desktop and mobile applications to record the heart rate signal only store data, without considering the person's activity when data are being acquired; they do not store, for example, if the subject is resting, watching TV or doing exercise. In the field of emotional stimuli, these software tools do not take into consideration if subjects are experiencing a specific reaction to a particular stimulus, for example visual or auditive. As stated before, HRV may be an indicative of reactions to different external stimuli. Keeping in mind this idea, it could be interesting to evaluate the effects of visual or auditive stimulation on HRV, as well as to study the variations in heart rate in different fields and situations. To reach this goal, the existence of a software tool to record the heart rate signal when the person is subjected to different external stimuli and situations could be very useful.

The lack of common software tools dedicated to this task makes it difficult for researchers to record the heart rate under emotional distress in an uniform, standard way. One of the solutions adopted by the majority of the scientific groups is to develop their own specific computer programs, which are not always freely available for the researchers community.

To overcome the limitation in the acquisition of the heart rate signal when different inputs produce emotional responses, for a later HRV analysis, we have recently developed the VARVI (Variability of the heArt Rate in response to Visual stImuli) tool [19] (gvarvi.milegroup.net). It is a software package that allows to record the heart rate signal, and to study heart rate variations and HRV parameters related with external visual stimuli, employing other software tools previously implemented in our group [20], [21].

VARVI was designed as a tool that would allow the recording of the heart rate while the subject was watching a series of videos or pictures. The acquisition of the heart rate signal is performed employing a specific sensor, a Polar WearLink chest strap with Bluetooth connectivity (www.polar.com/en/products/accessories/Polar_WearLink_transmitter_with_Bluetooth). The user has also the possibility to assign specific tags to the different videos or groups of pictures, according to their emotional contents. Those videos and pictures can be displayed in either an established or random order.

However, some aspects of the current VARVI tool deserve comment. First of all, it is only limited to the Polar WearLink chest strap, making it impossible its use with other connection devices. Second, only videos and images are considered to be presented to the subject, but no sounds can be added to the picture presentations. Third, VARVI lacks a graphical user interface (GUI). The user interacts with the computerized tool by a command-line interface and thus, VARVI is not an attractive tool for nonspecialized users, since its use is not as simple as a program disposing of a GUI.

In this work we present gVARVI, an attempt to solve the limitations of the VARVI software. In this way, gVARVI is a user-friendly software tool, provided with a GUI easily configurable by the user, and designed to capture the heart rate signal employing different chest straps sensor, specifically those working under the ANT+ protocol. Furthermore, VARVI allows to reproduce either visual or auditive stimuli to label them by their contents, and even to create activities, described later in the text, to better organize the acquisition task.

The rest of the paper is organized as follows. Sections 2 and 3 presents the general description and features of gVARVI, and technical aspects, including technologies and system architecture. Section 4 describes a practical use of gVARVI. Finally, conclusions and future work are presented in Section 5.

2. Software description

The main goal of the gVARVI tool is the recording of a heart rate signal when the person is doing a specific activity and to allow a later analysis of data. The application was initially designed to work with visual stimuli activities (the individual was subject to view different videos or photographs); however, in this version, more and different types of activities are allowed.

Each activity is composed of a sequence of actions (multimedia contents reproduction, texts on the screen, etc.). As shown in Figure 1, each action is represented by tag. The application can receive the heart rate signal from different kind of devices while the subject is under the influence of the different stimuli composing the activity. To reach this goal, a chest strap with either Bluetooth or ANT+ protocols must be placed on the chest of each person. This noninvasive sensor consists of two plastic electrode areas on the reverse side of the strap, that detect the heartbeats. It also has a transmitter that sends the heart rate signal to the computer, running the gVARVI application.

The activity to be controlled is first selected, and a "Begin" button is pressed; at this moment, the chest strap starts the heart rate acquisition. First, an identification code for data is required by the application. Next, gVARVI initiates the heart rate recording for each of the tags composing the activity. While the participant is doing the activity, the program communicates with the chest strap, stores the heart rate data in a file, and labels the different tags composing the activity. After each acquisition, two files are obtained. The first one contains the heart rate data information (distances between consecutive beats, in milliseconds), and the second includes the tags and time intervals (in seconds) corresponding to each of them. This information is needed to be able to separate, in the analysis step, data corresponding to each different tag.

gVARVI is designed to be a user-friendly, easy-to-use and -install application, and aimed at being employed by any user, independently from his/her experience with computers. Because of this, it includes a simple GUI, structured in four main areas (Figure 2).

These main areas will be described now:

- Activities: a list containing all the previous designed activities is displayed. Interactions with these activities can be obtained by pressing different buttons (details will be given in Section 2.1).

- Devices: a list with detected is shown, as well as the interaction buttons (an explanation appears in Section 2.2).

- Global Options: it includes buttons to access to preferences (language change, support for Bluetooth and/or ANT+, debugger activation, etc.), to access to "About" Section, and to close the application.

- Informations and Data Acquisition Start: it contains the activity name and device selected, as well as the button to start the data acquisition.

At the end of each acquisition, the user can generate a plot with the acquired heart rate data. Opening these data with the gHRV software tool is also allowed [21].

In the following paragraphs, a detailed explanation about activity and device management, as well as acquisition, data storage, and technical aspects, will be provided. The last subsection describes some additional functionalities of this software tool.

2.1. Activity management

An activity can be defined as a sequence of elementary and consecutive actions. The identificative name of each activity must be unique, and each of the actions must also have an identification name and a specific (finite) duration.

The definition of activities is saved in a persistent way, i.e., when an activity has been already created, it is not needed for the user to create it again in each new acquisition process. At present, the user can manage five different types of activities:

- Presentation of photographs: the user is viewing a set of pictures. Each tag represents a set of photographs stored in a folder. Moreover, a series of sounds can be added to each tag; sounds will be reproduced when the pictures associated to the tag are being viewed. The user can select if the tags are presented either sequentially (each tag in the order it appears in the activity definition) or randomly.

- Presentation of videos: a set of videos is presented. Each tag represents a video file. Similar to the former case, the presentation order can be either sequential or random.
- Presentation of sound: the main stimuli are sounds, and each tag will correspond to a sound file. Furthermore, a set of images can be associated to each tag; in this case, the pictures will be reproduced simultaneously with the sound file. If no images are associated, the screen remains black during the sounds reproductions, to avoid distractions. Once more time, sequential or random order presentation can be selected by the user.
- Set of actions controlled by the keyboard: in this activity, no audiovisual stimuli are shown. The screen only presented text defined and fixed by the user. Each tag contains a specific text and it is configured with an associated key. Let us suppose three different tags in the list TAG1, TAG2 and TAG3, each of them associated to different keys. The reproduction of the different tags begins with the first tag in the list, TAG1. The user can change to TAG2 by pressing its associated key, and change again to TAG3 by selecting the corresponding key. In this type of activity, the user can change to a tag previously reproduced, i.e., an execution TAG1 → TAG2 → TAG3 → TAG1 is allowed. With this type of activities, the user can control external events, with undefined duration. An example can be a physical activity with two different tags: TAG30 (30 repetitions of shoulder and upper arm stretch), and TAG10 (10 repetitions of ascending and descending of stairs). When the user finishes the first tag, he/she can press the key corresponding to the second tag, and begin ascending and descending stairs for 10 times. When this exercise is finished, the key for the first tag can be pressed again, until the user decides the activity has completely finished.
- Manual activity: similar to the activities controlled by the keyboard, no audiovisual stimuli are presented, and the screen shows a text previously fixed by the user, however, the reproduction is performed in a different way: each tag can finish when the user presses the space bar, but a finite duration can also be associated. With this activity, external events with a fixed duration can be employed, but the user can also decide their duration during the execution time. Moreover, the presentation order is known a priori. Let us suppose again TAG30 and TAG10. With the manual activity, the user could define an exercise as follows: TAG10, TAG20 (20 seconds length), TAG30, TAG25 (25 seconds length). Thus, the user would finish the tags TAG10 and TAG30 in a manual way, and both TAG20 and TAG25 would be automatically ended after 20 or 25 seconds, respectively.

Apart from these previous aspects, other features of the activities deserve comment. For example, they can be edited once they have been created. gVARVI also allows to export them (both the metadata and the multimedia files associated to the activities) to a single file. This can be useful when an experiment must be repeated using as executing devices different computers: the activity can be created only in one computer, the user can export it to the corresponding single file, and this file can be transmitted to the remaining computers, to be imported in each instance of gVARVI.

2.2. Device management

At present, gVARVI can deal with the sensors that capture the heart rate signal with the ANT+ protocol (`http://www.thisisant.com/`), as well as the PolarWearLink (`http://www.polar.com`), that employs the Bluetooth protocol. The user can scan the available devices from the main window of the gVARVI tool, and an option to test them ("Test" button) is also enabled. This allows to show in real time the data sent by the sensor, in order to verify if it is transmitting in a correct way.

2.3. Acquisition and Storage

To start with the recording of heart rate signal, it is needed the existence of a chosen activity, as well as the selection of the adequate sensor. When the "Begin" button is pressed, the program asks for an identification name for the recording, and starts the heart rate data acquisition. Simultaneously, the applications begins the reproduction of the selected activity. When this finishes, gVARVI stores the signal in a file, and also offers the user two possibilities (figure 3):

1. Plotting the acquired data, to verify the correction of the acquisition process.
2. Opening the gHRV tool to analyze the heart rate data.

The acquired data are then stored in two files (Table 1). The first one contains the information of the tags that compose the activity (with extension .tag.txt), including, for each tag, name and duration in seconds. The other file (with extension .rr.txt) contains the heart rate data information, specifically, the distances between consecutive beats (RR distance in miliseconds) are stored.

Moreover, a demonstration mode (demo mode) can also be executed; this special mode allows to carry out an acquisition without connecting to any physical device. To perform this task, a connection with a device is simulated by the software, and the heart rate data are randomly generated. In this way, the user can verify if the created activity is being reproduced in a correct manner, without placing the chest strap over the participant.

2.4. Technical aspects

The application was developed using Python programming language (`www.python.org`), which gives clean and legible code, easing software maintenance. It is based on the "batteries included" philosophy, which means that it provides a standard, and versatile library, and the user does not need to download additional software in most cases. Due to the existence of a great Python community, an extensive amount of code is also at the users' disposal, as well as forums, wikis, etc.

Related to the gVARVI implementation, the software structure is modular, and designed to allow future modifications in a simple way. The visual layer is completely separated from the logic layer, and inside each layer the functionalities are separated into modules. For example, in the view layer the configuration and management windows are separated from the activity reproductors. In the logic layer, the functionalities related with the acquisition devices, activities and persistence of both configuration and activities are also separated from the storage of the acquired data in the .tag.txt and .rr.tag files (Figure 4).

To implement visual interface, the graphic library wxPython (`www.wxpython.org`) was employed; it is opensource and allow the interfaces to adapt to the look and feel of the operating system. The contents reproductors employ the Pygame (`www.pygame.org`) library to present photographs and texts, and also to reproduce sounds. To present videos, the VLC bindings were used, in combination with Pygame. Matplotlib library was used for the graphical representation of data.

The libraries PyBluez (for the Polar WearLink chest strap) and python-ant (for the ANT+ devices) are used to connect with the acquisition devices. These libraries are only fully tested in Linux. Because of that, gVARVI runs successfuly in this operative system, but with more difficulties in other system like Microsoft Windows. gVARVI can be downloaded as a debian package from webpage `http://gvarvi.milegroup.net`. Installation in Windows requires technical knowledge.

2.5. Additional functionality

gVARVI supports multilanguage. At present, the available languages are Spanish and English. Furthermore, it has an automatic updating system, indicating to the user if a new version exists, and the way it must be installed.

It also offers a triple debugging system. On the one hand, the information of the running application is sent to the standard output. On the other hand, the application has a menu to activate a debugging window, where running data can also be observed. Finally, gVARVI provides a remote debugging system that allows to send the logs through the network, to be analyzed by the application developers.

3. Usability test

As we have mentioned before, gVARVI has an user-friendly and easy to use interface. To appraise this aspect, we have designed a usability test based on the Computer System Usability Questionnaire [22]. We have selected 9 out of the 19 questions of the original questionnaire, because some of them were not appropriate for our software tool. These are resulting questions:

1. Overall, I am satisfied with the ease of use of the system.
2. I feel comfortable using this system.
3. I can effectively complete my work using this system.
4. It was easy to learn to use this system.

5. The system gives error messages that clearly tell me how to fix problems.
6. The information provided for the system is easy to understand.
7. The organization of information on the system screens is clear.
8. The interface of this system is pleasant.
9. Overall, I am satisfied with this system.

Each question had to be evaluated with a score between 1 (strongly disagree) and 5 (strongly agree). The questionnaire was completed by fifteen volunteers. As we can see in Figure 5, all questions had pretty good scores, with an average of more than 4.5. Only questions 7 and 8 had some scores below 4 in an answer.

Questionnaire form had also a comments section, where volunteers reported application failures and they proposed improvements in user interface design. They also suggested new features. Some of these suggestions were included in the last version. For example, the dialog shown at the end of the acquisition was redesigned to allow users to select more than one option, so now users can plot results, open them in gHRV and open both the .tag.txt file and the .rr.txt file in a text reader simultaneously. In the last version users can open recent acquisitions as well.

Other suggestions were taken into account for future versions. For example, some users proposed an option to perform series of experiments, giving automatic names to the files obtained. Future versions will include all these improvements.

4. A sample run

In order to show the capabilities of gVARVI in this Section we show how to design a complete activity, to acquire the heart rate data and to plot the results. It is known that heart rate is different when a person is relaxed than when he/she is in a stressful state. Keeping this in mind, we have developed a simple experiment to obtain heart rate data in both situations.

We have used the "sound presentation" activity. The first tag of the activity was a relaxing sound, and the second was a scaring one. We have also accompanied both sounds with images to increase each feeling. For example, the relaxing sound was accompanied by a mix of beautiful landscapes, zen pictures, and people in relaxing poses. On the other hand, the scary sound was accompanied by haunted houses, devilish dolls and people with scary faces. Sounds were about 3:30 minutes long, and each sound had associated about 20 pictures, so each picture was 10 seconds long. The activity file used in this sample run can be downloaded from the webpage `http://gvarvi.milegroup.com`.

A picture of an individual acquisition for this experiment is shown in Figure 6. The results are shown in Figure 7. After that, a software such as gHRV could be used to analyze these results and make a diagnosis.

5. Conclusions

In this paper an open source software tool to record the heart rate while a person performs an activity is presented. This tool allows to design activities, and also manages experiments in which the heart rate is recorded in real time, while the subject carries out an activity composed of different actions. gVARVI is the evolution of a previous tool, VARVI, with some improvements, such as a graphical interface, a more complete set of activities to manage, support of more devices, a new log system and multilanguage support

The usability test proves that it is a comfortable tool even for nonspecialized, computer expert users. Furthermore suggestions provided by volunteers performing this usability test have allowed us to improve some functionalities and schedule some others for future releases.

Records obtained with this tool are compatible with other software tools for HRV analisys, developed by our research group, such as RHRV and gHRV. At present all these tools are being used by psychiatrists and communications researchers. In a near future they will be used in some experiments in sport science.

Among the improvements to be included in next releases, some deserve comment: the capability of designing mixed activities, composed of different kind of actions, such as some video sequences and a keyboard controlled action. A Microsoft Windows installer is also scheduled for next releases.

Due to the modular architecture of gVARVI, it is possible to re-use its different components to develop new tools. The acquisition module coud be used in a new heart rate monitoring application in sports. The activity management module could also be adapted to other devices, like dermic conductance sensors or encephalographs.

Acknowledgements

We would like to acknowledge the volunteers that have tested this tool and gave us useful feedback to fix bugs and improve some functionalities.

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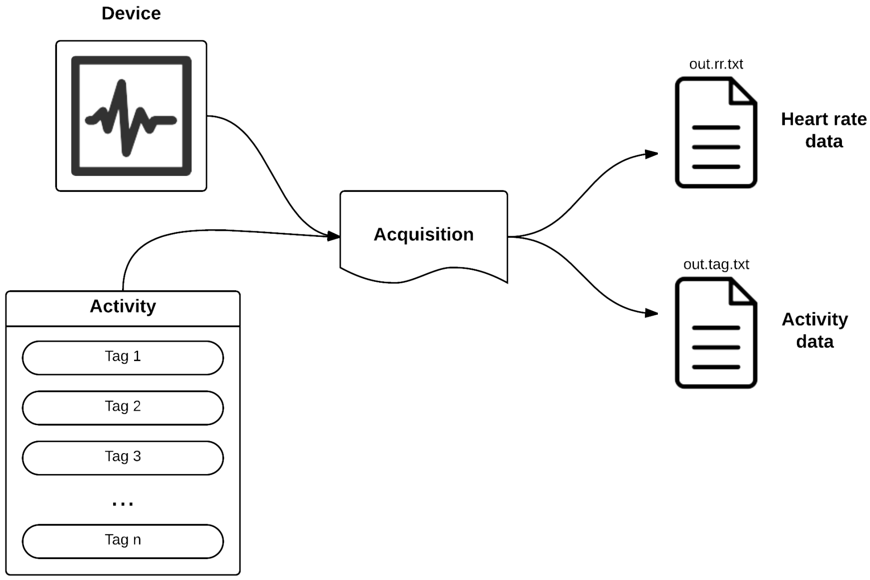

Figure 1: Scheme of the gVARVI application.

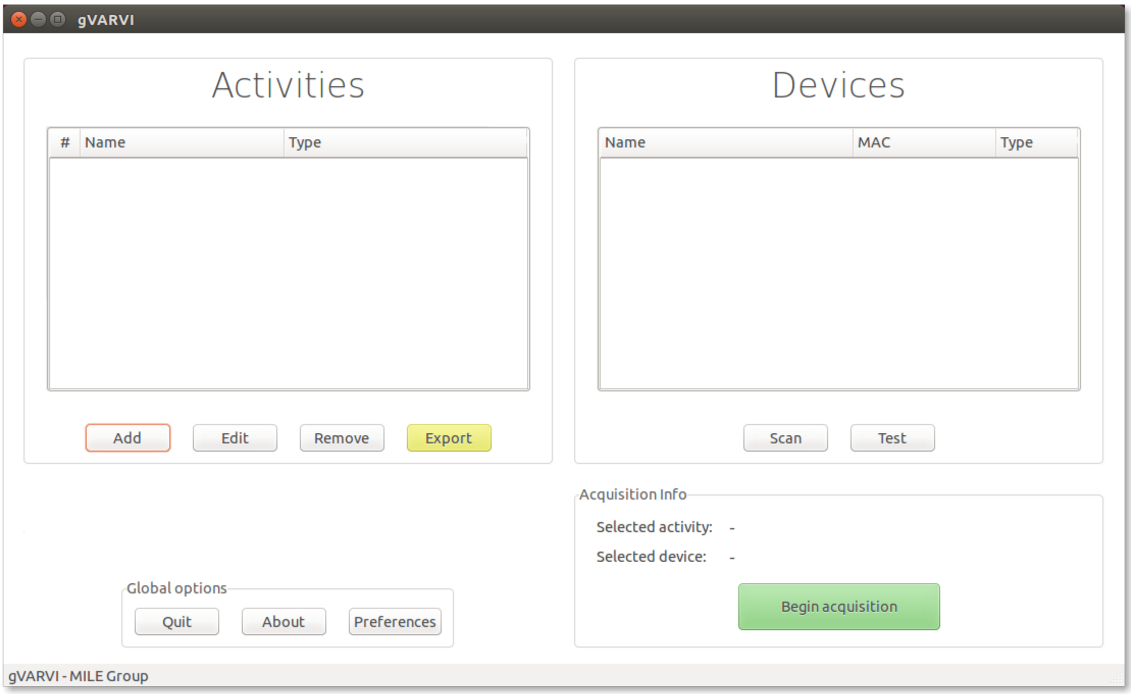

Figure 2: Initial screen of the gVARVI application.

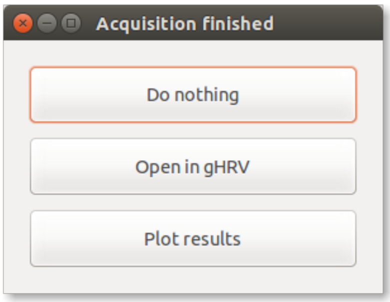

Figure 3: Dialog shown at the end of the acquisition.

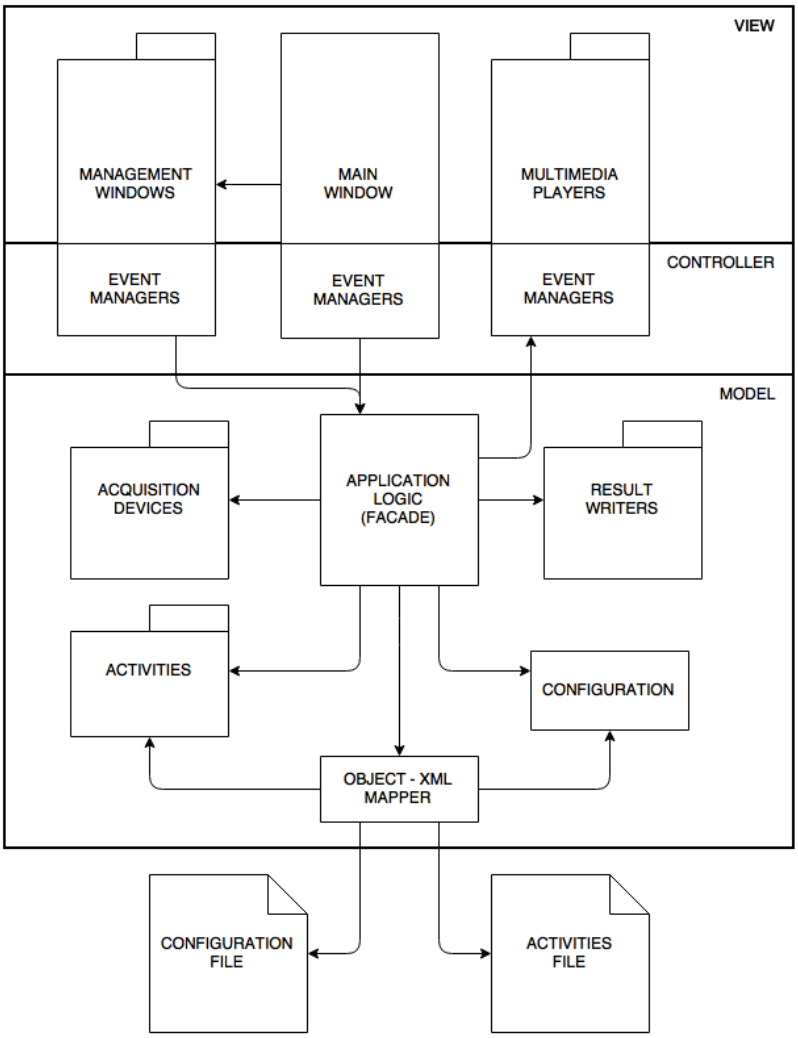

Figure 4: gVARVI architecture.

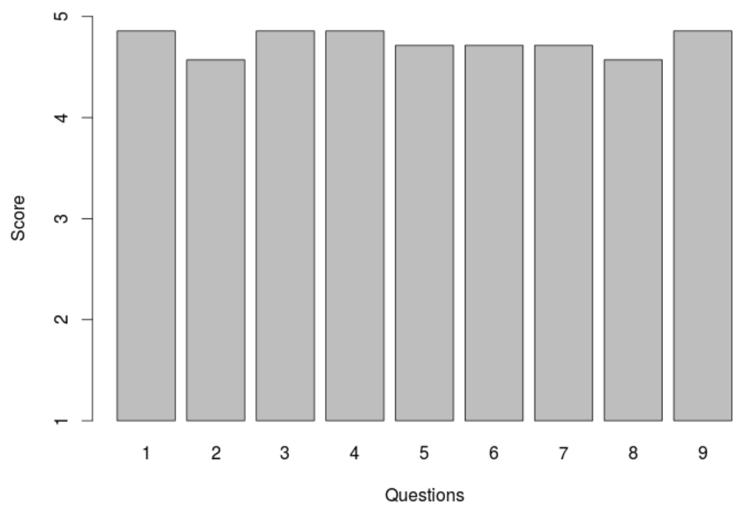

Figure 5: Average score for each question of the usability test.

Figure 6: A volunteer doing the experiment with gVARVI.

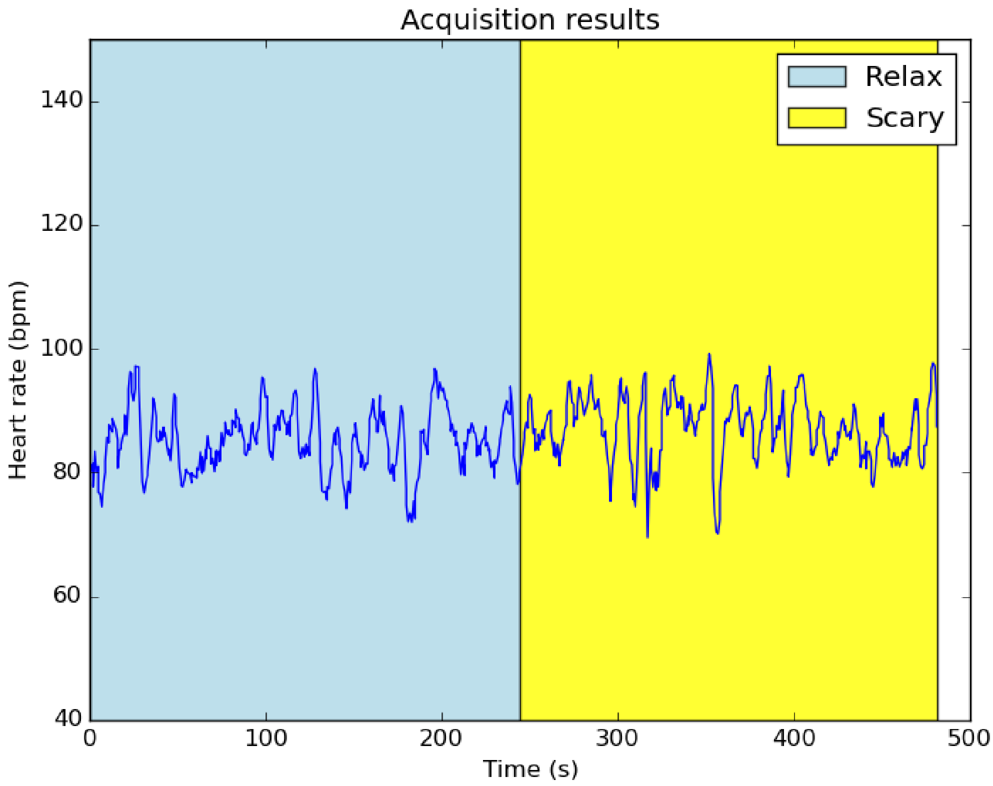

Figure 7: Acquisition results plot.

rr file *(sample.rr.txt)*	tag file *(sample.tag.txt)*		
822			
881			
891	Init_time	Event	Durat
813	0:00:00.034626	Relax	244.161374
803	0:04:04.215514	Scary	237.280473
894			
838			
...			

Table 1: Result files (from a sample acquisition using the experiment explained in section 4)