Physiological Computing Gaming
Use of Electrocardiogram as an Input for Video Gaming

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Abstract: There are several ways of creating a human-computer interaction (HCI). One of those is physiological computing (PC) i.e. the use of body signals as a real-time input to control a user interface. In this paper one describes the development of a new solution in which electrocardiography (ECG) signals are used as input for video gaming. The solution includes: a tailored belt with conductive textiles as ECG electrodes; a specialized data acquisition board (Bitalino); signal processing algorithms implemented in Python for signal filtering, QRS complex detection and heart rate calculation; and use of Unity 3D, a game development engine, in which the heart rate is used as an input of a proof-of-concept PC video game – FlappyHeartPC. With this project we conclude that nowadays it is possible to build tools that can make the bridge between the machine and the human body in order to respond to innovations required in the gaming business.

1 INTRODUCTION

Innovative technologies are increasing their presence in every field of living. Spending free time in front of a computer or a television is far more common than several years ago and has become an essential part of modern lifestyle. Of particular relevance in this context is physiological computing (PC) which has enormous potential to innovate human–computer interaction (HCI) by extending the communication bandwidth between humans and computers, enabling the development of "smart" technologies (Hettinger, 2003). Here, HCI is achieved by analyzing and responding to covert psychophysiological activity from the user in real-time (Fairclough, 2009). Probably one of the most common biosignals that can be used as an input for PC is the Electrocardiogram, which is commonly used to access the overall cardiac condition. In new-born infants, the resting heart rate is commonly 120 beats per minute (bpm) or higher, and it declines with age to 72-80 bpm in young adult females and 64-72 bpm in young adult males. Nonetheless, heart rate changes during physical activity, fatigue or when experiencing emotions. It can be also changed due to cardiovascular diseases (Ostchega, 2011). Factors that raise the heart rate are called positive chronotropic agents, and factors that lower it are known as negative chronotropic agents. Although the nervous system does not initiate the heartbeat, it can modulate its force and rhythm (Goldberger, 1991). Some neurons in cardiac centers have a cardiostimulatory effect transmitting signals to the heart via the sympathetic pathway, others communicated to the heart via the vagus nerves (Pokrovskii, 2005).

Sensory and emotional stimuli can then act on the heart rate via the cerebral cortex, limbic system, and hypothalamus. Hence, heart rate can rapidly change during "fight or fly" situations or during workout, and is influenced by emotions, such as love or anger (Porges, 1991; Wiltbank, 2008).

During workout, proprioceptors in the muscles and chemoreceptors (De Burgh Daly, 1958; Hutton, 1992) transmit signals to the cardiac centers, translating muscle activity; thus sympathetic output from the cardiac centers increases cardiac output to meet the expected demands. Endurance athletes can have resting heart rates as low as 40 to 60 bpm, even though, due to the higher stroke volumes, their resting cardiac output is about the same as that of an untrained person. Such athletes have a bigger cardiac reserve, so they can tolerate more exertion than a sedentary person can (Sandercock, 2005).

Electrocardiography (ECG) measurements can be divided into "fixed-on-body" measurements with

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silver/silver chloride ($Ag/AgCl$) electrodes, and fixed-in-the-environment electrodes. Although fixed-on-body electrodes are reliable and give good signal quality, fixed-in-the-environment electrodes' nature makes them an attractive option for daily monitoring (Lim, 2006).

Advances in computation and integrated circuits capabilities allow videogames to be more emotionally engaging. Still, at the moment, these interactions are based purely on the input the player consciously decides to use in the game world (i.e. actions executed through the game controller). However, there are unseen physiological responses (e.g. heart rate variations) taking place within the player's body as well as various behavioral responses (e.g. gestures, facial expressions, body postures). Such responses are useful in identifying the current emotional state of the player. The form of gameplay where this information is collected is commonly referred to as affective gaming, in which the player's emotional state is used to influence gameplay.

From the perspective of emotion recognition technology, affective gaming is related to biofeedback systems, where people 'learn' how to control physiological activity such as heart rate, muscular action, or brain waves by being provided with real-time graphical representations of their biometric state. The main goal of this work was to test the usability of an ECG signal as an input for gaming. For that purpose a game called FlappyHeartPC was developed.

2 MATERIALS AND METHODS

A. Belt Design

Bearing in mind experiences of other researchers (Holley, 1990; Milis, 1979; Misczynski, 2005; Muhlsteff, 2004), we decided to use electroconductive textiles instead of conventional $Ag/AgCl$ electrodes. Textile electrodes are a new potential choice for biomedical measurements and their medical usage was proven during motion analysis with great success (Lourenço, 2012; Pola, 2007). Using electro-textile electrodes as the interface between the sensor and the skin, it allows the improvement of signal acquisition methods for ECG biometrics, targeting wearable, and unobtrusive and continuous applications (Silva, 2011). This electroconductive textile is a highly conductive lycra made from silver wires woven with nylon (MedTex™ P-130). Up to date, there is no proof that electrolycra may cause any skin irritation. The prototype belt is also composed of: elastic rubber-textile material (allows the belt to adhere strictly to the body, which is the condition for an accurate measurement), non-elastic knitted fabric (assures the same position of the electrodes) and Velcro® (fixing to the body and locking).

Thanks to its construction, the belt can be used by a widely range of people, maintaining the same position during breathing or workout (Figure 1).

B. Signal Acquisition – *Bitalino*® Board

Inspired by the Maker and DIY movements we choose not to use commercially available Bluetooth

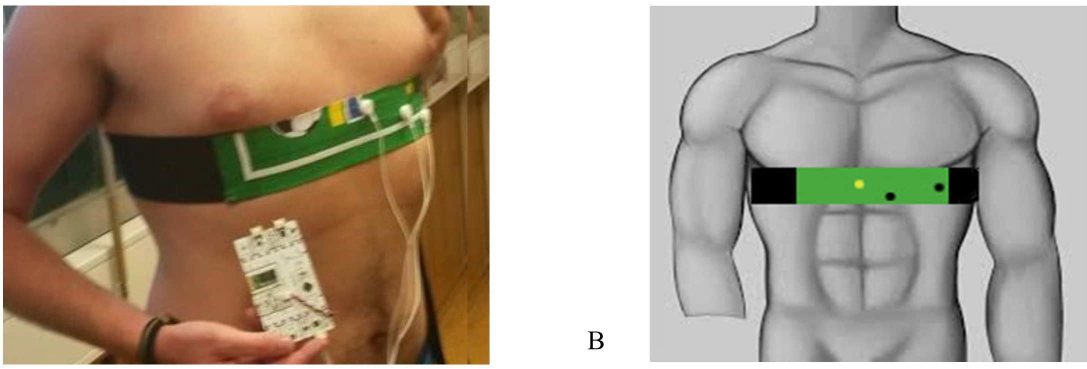

Figure 1: A. Experimental setting of the belt position, with one electrode at the sternum and the other two in the two sides of the heart, with the belt connected to Bitalino®. B. Schematic of the belt positioning. The yellow dot represents the "ground" electrode, and black dots correspond to the positive electrode (placed at the 4^{th} intercostal space near the sternum) and the negative electrode (placed at the 4^{th} intercostal space midclavicular line). The green rectangle corresponds to non-elastic knitted fabric; the remaining black strips correspond to rubber-like elastic material.

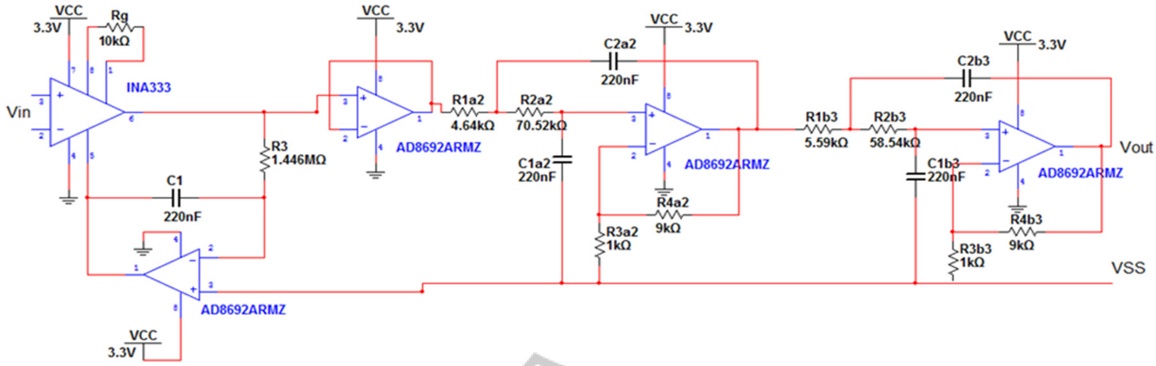

Figure 2: Electrical circuit used in Bitalino for ECG measurement.

ECG medical hardware. Therefore, for acquiring the ECG signals we used the Bitalino®, a low-cost platform, targeted at multimodal biosignal acquisition, that can interface with other devices, or perform rapid prototyping of end-user applications in the field of PC (Guerreiro, 2013). Its electrical system is represented in Figure 2. The board includes the electrical ECG circuit represented in Figure 2. Since this was a proof-of-concept study we used the conjugation of the electrolycra belt with the Bitalino® to measure the ECG of only two subjects (subject 1 – Male, 22 years old, 85 kg; subject 2 –Male, 22 years old, 73kg). All signals were acquired with a sampling rate 1 kHz. During testing of the electrolycra belt, ECG measurements were also done using conventional Ag/AgCl electrodes for qualitative performance comparison.

C. Algorithm Explanation

Software for signal acquisition and processing was developed in Python language (Enthought Canopy Distribution), which includes numerous already written packages designed for numerical data analysis, signal processing or graphics design. There are several possible algorithms for detecting the QRS complex (Afonso, 1993) that could be used with this platform. After testing with different algorithms we chose the following approach:

First, the signals were recorded and opened by Python software, in which each 10 s of the data were processed and analyzed. The DC component and power-line interference was removed using a Notch filter at 50Hz. Then, the signal was filtered by a series of Finite Impulse Response (FIR) filters. These filters require more memory than Infinite Impulse Response (IIR) filters, but have no feedback elements, which makes them stable.

Subsequently, a lowpass filter (cutoff 20 Hz, Blackman & Harris window, 61 order), followed by a highpass filter (cutoff 15 Hz, Blackman & Harris window, 61 order) (Pan, 1985) were applied. Digital filters frequency response is presented in Figure 3.

The next step of the algorithm was 'thresholding' the unwanted part of the rectified signal. The threshold is set up to 30% of the maximum magnitude of the 10 s piece of the signal (Christov, 2004), which removes unwanted components of the signal. Before detection of the peaks, an additional smoothing with a lowpass filter with cutoff frequency equal to 2 Hz and order 100 was done.

The last step of the signal processing program is peak detection. In this work two methods for peak detection were studied: differentiation and wavelet-based peak detector from the scipy.signal python library (Du, 2006). The general approach of the latter method is to perform a continuous wavelet transform on data vector. In this work the Ricker wavelet, also known as Mexican Hat wavelet was used with an array of integers range from 70 to 100 as widths. Regarding the differentiation method, a function that generates a nonzero array, detects the difference between consecutive array values, and adds that position to the array if the sign changed from positive to negative, was implemented. This method easily detects the local maxima of the signal (Afonso, 1993).

The accuracy and the computational performance of peak detection algorithms was then evaluated and compared using two 3-minute recordings for each subject.

Finally, computing a heart rate was simply measuring the time between each peak and converting it to bpm. The heart rate value was then used as a game input.

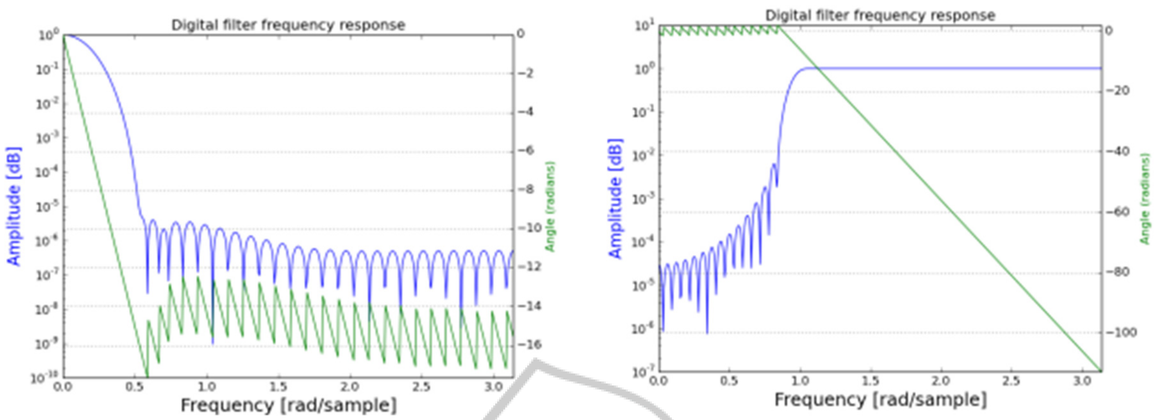

Figure 3: Designed filters: lowpass filter – cutoff 20 Hz (left) and highpass filter (right) – cutoff 15 Hz.

D. Unity – 3D Game Engine and PC Game Development – FlappyHeartPC

Unity 3D is a game development ecosystem, a rendering engine integrated with a set of intuitive tools and workflows to create interactive 3D and 2D content. Additionally, it offers the possibility of physical simulations, working upon mechanical laws.

For the proof-of-concept of this work we decided to design a PC game named FlappyHeartPC in which the heart rate is translated into the speed of the heart game character (Figure 4). The inspiration for this game was the FlappyBird™ game.

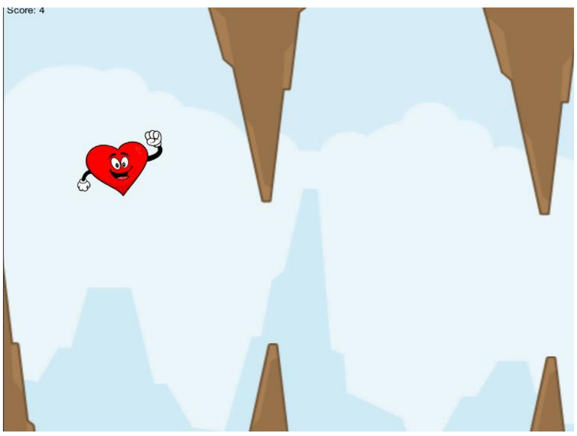

Figure 4: Screenshot of the FlappyHeartPC game. Background and rocks cc0 licence from Kenney Vleugels.

Thanks to the low complexity of the game, we were able to focus more on the implementation of the PC interface and playability. Due to incompatibility of Python language with Unity 3D (which supports C# and JavaScript) the output of the processing algorithm was in the form of a .txt file, which can be imported by the game engine. In order to enhance the PC aspect of the game, we assumed that the players' heart rate was between 50-100 bpm (Ostchega, 2011). The mass of the game character was set up as 1 [unit of mass in Unity 3D space] and gravity as 1 [unit of gravity in Unity 3D space]. Then the player's heart rate was assigned to the following thresholds; determining the speed (Units/Frame) of the game character, see Table 1.

Table 1: Player's heart rate and following thresholds for the Units/Frame.

Hearth rate	<50	50<60	60<70	70<80
Units/Frame	0.5	1	2	3
Hearth rate	80<90	90<100	=>100	
Units/Frame	4	5	6	

The goal of the game is to survive as long as it is possible, avoiding collision with obstacles. The gaps between obstacles were chosen randomly. Here, the higher the heart rate is, the faster the game character moves. This makes the game more difficult and therefore it induces the player to maintain a low heart rate level to increase the chances of survival.

3 RESULTS

Figure 5 show ECG signals recorded using conventional Ag/AgCl electrodes and using the electrolycra electrodes. Although electrolycra signals seem to have smaller signal-to-noise ratio than the ones obtained using conventional electrodes, the QRS complex can be easily identified. Figure 6 shows that after signal processing, the QRS complex detection is achieved using electrolycra signals. Both wavelet and

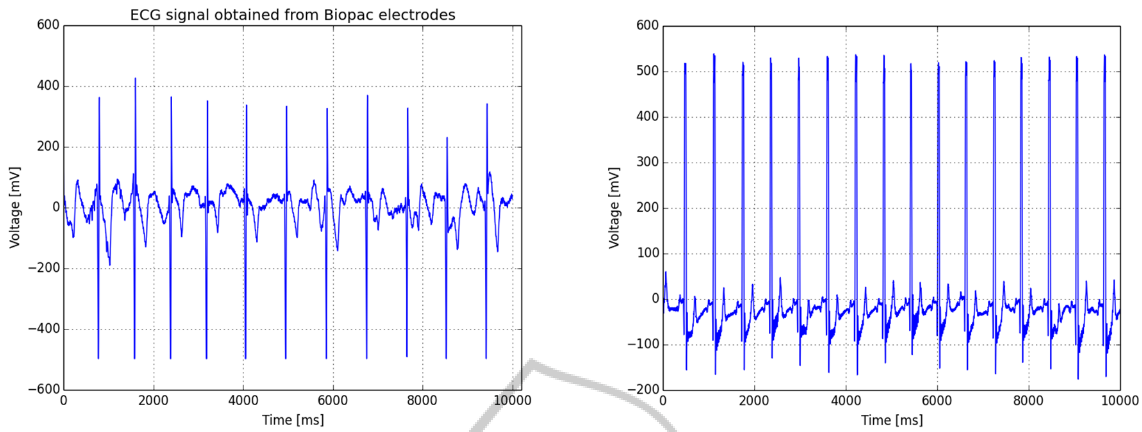

Figure 5: ECG signal recorded by Ag/AgCl electrodes (left) and the belt with electrolycra electrodes (right).

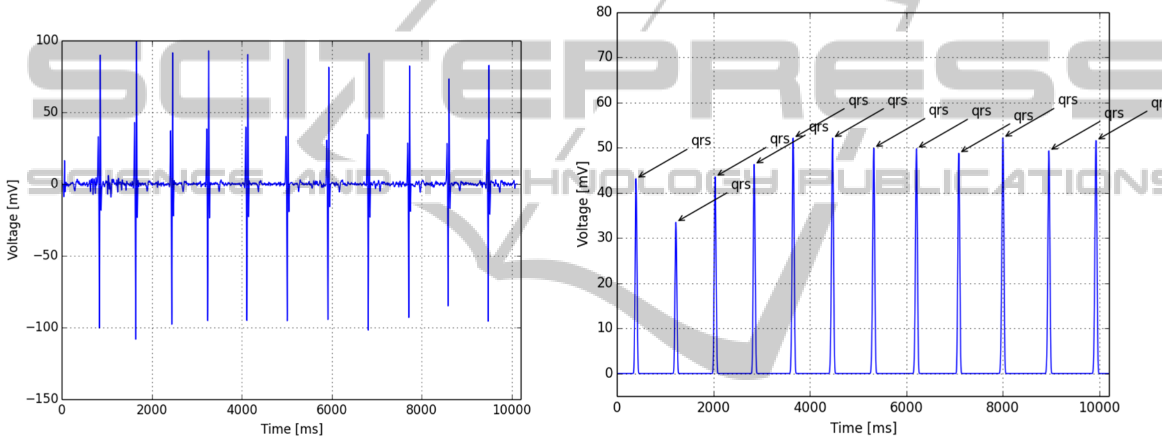

Figure 6: ECG signal after filtering (left) and final example of QRS complex detection (right).

differentiation based peak detection algorithms were tested: the wavelets algorithm obtained 91,4%, accuracy and 95,9 % precision. The differentiation algorithm, on the other hand, obtained 90,6% of accuracy and 90,6 % precision but was computationally faster (10 s of ECG data processed in 1.2 s vs 7.8 s using the wavelets-based method). Therefore, the differentiation algorithm was chosen for the final version of the game.

4 DISCUSSION

A. Belt Design

One of the most important challenges in belt design was to make it suitable for several people and minimize the noise during signal acquisition. The first one was solved using elastic rubber-like material with Velcro®. The second challenge required using electroconductive thread, instead of traditional cotton one, for connecting the electrolycra electrodes to the Bitalino® cables. Then the belt, as a first implementation, showed that with low cost material it is possible to obtain suitable ECG signals.

B. Game Design

Due to being just a proof-of-concept study we decided to design the game as simple as possible. Still the FlappyHeartPC game plays well its role as an implementation of physiological signal input into a game environment.

However, it has to be mentioned that people with tachycardia (increased heart rate) or with cardiovascular diseases (such as arrhythmia) may have difficulties playing the game due to harder peak detection.

According to subject 1, FlappyHeartPC game was “an interesting experience”. The most important factors in the game mentioned were “simplicity of the gameplay" and the fact that the game "promotes competition between players".

Subject 2 focused mostly on the PC side of the game. According to him, after "becoming familiar with game properties" it promotes players who are able to "control heart rate, by meditation".

C. Analysis of Signal Processing Results

Signal acquisition and preprocessing appeared to be rather well developed; still the most challenging part was related to the detection of the QRS complexes and measuring the duration between them.

As mentioned before, the wavelet-based algorithm obtained 91,4% accuracy, whereas the differentiation algorithm was slightly less accurate reaching 90,6% of accuracy. However, this method was computationally simpler to implement and was less memory demanding than the one based on wavelets. It has to be mentioned, though, that in both algorithms the number of false-positive peaks detected can be minimized using a false positive peaks removal algorithm (Du, 2006).

From the signal processing point-of-view both methods for detecting the QRS complex could be taken into account. Nonetheless, for the gaming industry time of response and dynamics of the program are more important than accuracy. Due to the fact that wavelet transform processing times (10 s of data in 7.8 s) is almost 8-fold larger than for the differentiation algorithm (10 s of data in 1.2 s), this latter algorithm was preferred for use in the final version of the game.

D. Possibilities and Future Improvements

During this project we focused on creating an additional dimension in gaming. In general we hope that this work contributes to the widespread use of PC in the gaming industry, which is thought to continue to be one of the most profitable businesses in years to come. Now we are going to discuss briefly about the future possible usages for our belt and the PC platform, which are:

Fatigue detector: when computing heart rate and breathing it is possible to calculate and predict the level of fatigue for the current player. Similar approaches are used nowadays in modern sports laboratories, but with the use of electrodes and wires. Combining this tool with *Microsoft® Kinect®* technology, will allow the creation of a real virtual representation of the human body, including the real stamina of the person. Thus, the possibility of using our belt in a game would be an improvement over existing games, allowing for a much more realistic experience. Additionally, the belt and PC platform could be used also in the medical field, as a feedback for workout or rehabilitation. In that case, games would complement the role of the physiotherapist or trainer, both motivating and controlling correctness of the movement (Marozas, 2011).

PC gaming with Unity 3D or other platforms: one of the most obvious possible improvements is to create an add-on or plugin to Unity 3D with the integrated heart rate detection algorithm, which will make the FlappyHeartPC, or any designed game available for the market. This approach would focus on increasing the playability of the games, making them more enjoyable, interesting and fitting each player. This would also make games more diverse and different each time the game is played.

Long term, portable monitoring of human body signals: people with cardiac or breathing problems usually have to go to a hospital for long and exhausting monitoring. By making use of portable monitors, patients could regain their autonomy. Our belt and PC platform could be one good solution to address this issue if given phone or internet communication capabilities. Thus, data could be recorded and sent to medical doctors for evaluation. This approach could also be used for monitoring the elderly and isolated patients and inform the hospital about arising problems. This could be a means to increase the chances to survival for these patients.

5 CONCLUSIONS

This project is a starting point for futures studies in the field of HCI. It is already possible to infer that with information from our physiology as input (heart rate) it is possible to change the dynamics of a game environment using a low-cost tool such as *Bitalino®*.

For future investigations more tests are required, e.g. more data has to be acquired and analyzed. For further work the most reasonable upgrade is integrating signal processing within Unity 3D software, which will make the game more stable, and versatile. Additionally, in the long run, this type of game applications can have an interesting role in rehabilitation and physiotherapy.

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