PROTOTIPO DE BAJO COSTO PARA APLICACIONES DE BIOFEEDBACK

Low-cost prototype for biofeedback applications

SERGIO CANO
Estudiante
Ingeniería Electrónica
Universidad de Nariño
sergiocano@udenar.edu.co

DIEGO PELUFFO
Ingeniero electrónico, Ph. D.
Profesor
Facultad de Ingeniería
Universidad Cooperativa de Colombia - Pasto
diego.peluffo@campusucc.edu.co

JAVIER REVELO
Ingeniero electrónico, Ph. D.
Director programa Ing. Electónica
Facultad de Ingeniería
Universidad de Nariño - Pasto
javierrevelof@udenar.edu.co

ÁNGELA RUANO
Estudiante
Ingeniería Electrónica
Universidad de Nariño
angelarg@udenar.edu.co

RESUMEN
Este trabajo presenta el diseño de un prototipo de bajo costo para aplicaciones de biofeedback basado en la frecuencia cardiaca estimada por fotopletismografía. El prototipo propuesto involucra principalmente dos bloques constructivos: El primero de ellos se ocupa de la adquisición y filtrado análogo de la señal. Mientras tanto, el segundo bloque consiste en la estimación de la frecuencia cardiaca y la retroalimentación visual, implementadas en una plataforma Arduino. Los resultados experimentales y pruebas muestran su utilidad, manteniendo el objetivo de involucrar bajos costos y portabilidad.

PALABRAS CLAVE: Biofeedback, fotopletismografía, frecuencia cardíaca, procesamiento, realimentación visual, sensor.

ABSTRACT
This work presents the design of a low-cost biofeedback prototype based on the heart rate estimated from photoplethysmography. Proposed prototype involves mainly two building blocks: The first one is concerned on the signal acquisition and analog filtering. Meanwhile, the second one is the estimation of heart rata and visual feedback implemented in an Arduino platform. Experimental results and tests show its usability keeping the goal of involving design low costs and portability.

KEYWORDS: Biofeedback, heart rate, infrared sensor, photoplethysmography, visual feedback.

1. INTRODUCTION

There are several attempts to integrate biomedical and psychological contributions to the study of health and disease aimed at not only doing treatments but also enhancing the skills of the patient [1, 2]. One of the approaches to do so is via biofeedback techniques, which involve biological activity measurements as well as feedback thereof [3]. Typically, such a feedback is done through visual [4] or auditory [5] stimuli. These techniques are based on psychological research and its regulatory relationship of physiological events from the autonomic physiological relevant to the health maintenance of the central nervous system, namely: heart rate, blood pressure, muscle tension, gastrointestinal activity, etc.

More technically, biofeedback is based on physiological measurements or signals, so they must be accurately measured/acquired, as any small change in physiological activity, e.g. rate heart or electrical skin activity, may be misinterpreted [6]. The physiological activity sensing and acquisition are conducted using technological tools providing accurate measurements [7, 8]. There exists a wide range of electronic devices and equipment for Biofeedback, being mostly expensive and non-modular designed.

In this work, we propose the design and implementation of a low-cost and modular biofeedback prototype developed in Arduino platform able to capture the physiological signal keeping a high level of reliability. Despite being low-cost, it includes in itself a module to carry out a visual biofeedback.

Briefly put, our prototype works as follows: The signal acquisition is grounded on the principle of photoplethysmography, which consists of impinging an infrared light ray on the skin and measuring changes in light absorption produced by the passage of blood through the tissues –it is done with a photoreceptor. Once acquired, signal is filtered and amplified by analog instrumentation devices. Then, it is processed by using programming routines. Such a processing stage allows for estimating the heart rate. Finally, visual feedback outputs are shown in a screen correspondingly to the estimated heart rate. Proposed prototype works properly within a wide range of heart rate levels, being then a good alternative to start with the applications for biofeedback therapy.

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The remaining of the paper is organized as follows: In section 2, materials and methods are outlined, describing the acquisition, filtering, signal processing and feedback stages involved in the design of the proposed biofeedback system. Section 3 shows experimental results. Finally, section 4 gathers some final remarks as conclusion and future work.

2. MATERIALS AND METHODS

To describe the operation of the proposed prototype two main building blocks are considered, the first of them consists of the signal acquisition and filtering stages, and the other one is responsible for stages of signal processing and visual feedback.

A 12V/1A direct current source is used as power supply for the Arduino device, which feeds the stages of signal acquisition and filtering with 5V/500mA.

Figure 1 depicts a descriptive diagram of the proposed biofeeedback system.

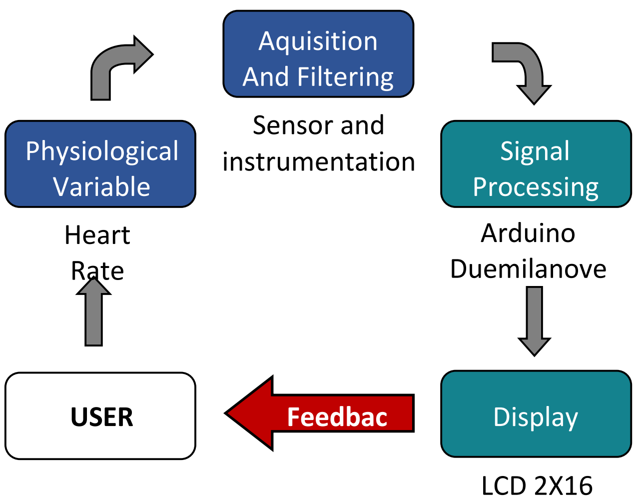

Figure 1: Block diagram of the proposed biofeedback system.

Following are described the system stages in detail.

2.1. ACQUISITION AND FILTERING

The signal acquisition is made in a non-invasive fashion, namely a pulse sensor is used, which is placed in one of the user's fingers (either index, middle or ring). Basically, it consists of an optoelectronic device working as emitter/receiver couple. The employed emitter is an infrared LED meanwhile the receiver is a standard phototransistor. Then, the signal to be processed in the filtering stage is provided by the infrared light variations detected by the phototransistor.

In this work, we perform an analog filtering process using a band-pass filter implemented in three steps. Firstly, a second order high pass filter (see Figure 2(a)) is used to remove the noise system caused by voltage

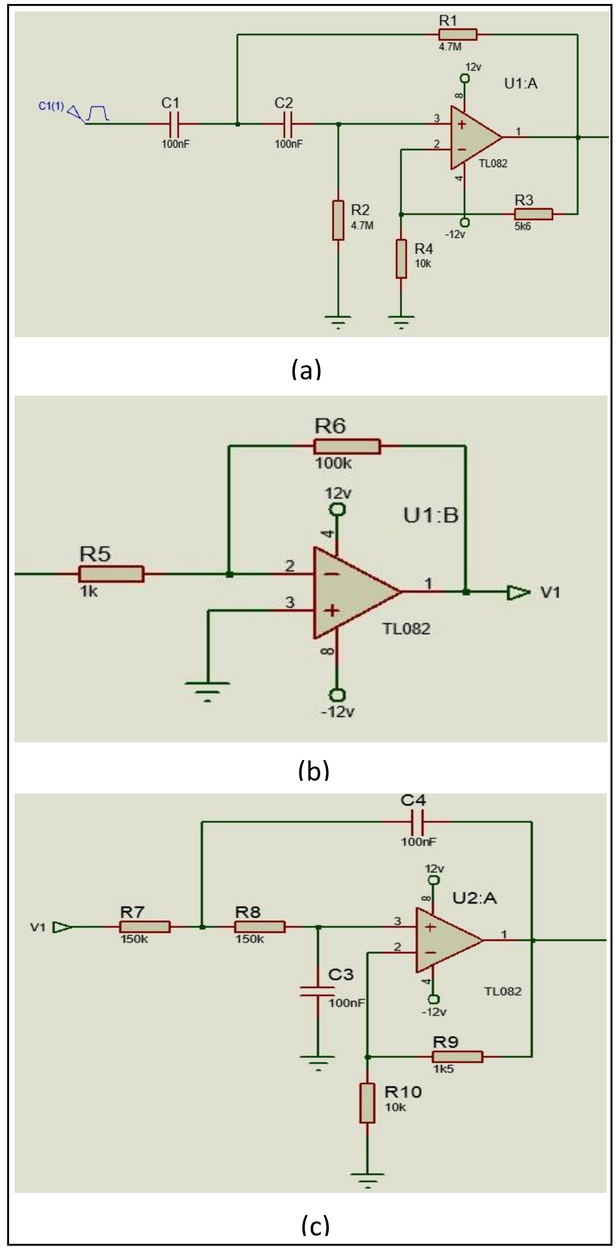

Figure 2: Filtering Stage: High pass filter (2(a)). Inverter amplifier (2(b)). Fourth order low pass filter (cascade of two second order filters) (2(c)).

variations due to the finger movement and the phototransistor DC polarization voltage. At this step, we can guarantee a right operation of the system avoiding the saturation of the next filtering step. Secondly, we implement a basic inverter amplifier with a gain of 100, as shown in Figure 2(b). Finally, a fourth order low pass filter (built as two second order low pass filters in cascade topology) is implemented to make the acquired signal more reliable by

keeping the substantial information of it and eliminating undesired signal components. In terms of an additive noise, this can be said to be a subtraction of terms

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unrelated (additional information) to the information of interest.

In this case, additional information is attributed to the high frequency noise caused by the electrical network and devices connected to it (e.g. the power sources), as well as the frequencies of other light sources that might be detected by the phototransistor.

Next, we perform some basic calculations to determine the parameters for both filters and the inverse amplifier. When analyzing the dc effects on the high pass filter, we have that the closed-loop gain is given by

$$Av = \frac{R_3 + R_4}{R_4}\,. \quad (1)$$

In order to get a gain of 15.6 v/v, we set $R_3 = 5.6K\Omega$ and $R_4 = 10K\Omega$. As well, the cutoff frequency can be estimated as:

$$fc = \frac{1}{2\pi\sqrt{C_1\,C_2 R_1 R_2}}\,. \quad (2)$$

To account for avoiding a 0 Hz reference, we choose $fc = 0.3$ Hz by setting $C_1 = C_2 = 100nF$, and $R_1 = R_2 = 4{,}7M\Omega$.

Since the amplification stage is carried out by a simple inverse amplifier with closed-loop gain

$$Av = \frac{-R_6}{R_5}\,, \quad (3)$$

We can ensure required 100 v/v gain by just selecting R6 and R5 as 100 K and 1 K, respectively.

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$$Av = \frac{-100K\Omega}{1K\Omega} = -100$$

In the first part of the cascade for the fourth order low pass filter, the calculation for the closed-loop gain is given by:

$$Av_1 = \frac{R_9 + R_{10}}{R_{10}} \quad (4)$$

So we get a gain of 1.15 v/v, seting $R_9 = 1.5K\Omega$ and $R_{10} = 10K\Omega$.

In the second part of the cascade, the closed-loop gain is calculated with:

$$Av_2 = \frac{R_{13} + R_{14}}{R_{14}} \quad (5)$$

Then the value for the obtained gain using $R_{13} = 13K\Omega$ and $R_{14} = 10K\Omega$ is 2.3 v/v

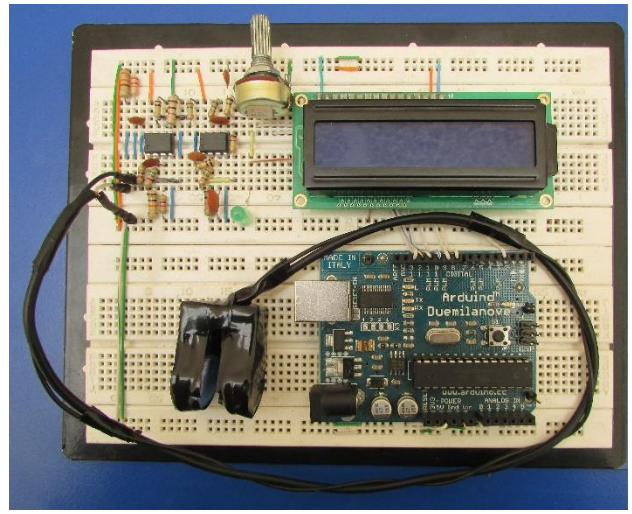

Figure 3: Biofeedback prototype implemented on a breadboard.

Finally the total gain of the cascade is calculated through:

$$Av = Av_1 \times Av_2 \quad (6)$$

Getting a value of 2.645.

The two low pass filters which constitute the cascade must have the same cutoff frequency value and it is calculated as:

$$f_{C1} = \frac{1}{2\pi\sqrt{C_3\,C_4 R_7 R_8}} \quad (7)$$

Obtainig a value for the cutoff frequency of

$$f_{C1} = 10{,}6Hz$$

2.2. SIGNAL PROCESSING AND VISUAL FEEDBACK

An Arduino Duemilanove data acquisition card is used for the signal digital processing. The obtained signal from the filtering stage is used to calculate the heart rate with a simple software algorithm that consists in dividing sixty seconds by the lapsed time between two high logical states (this time is computed using Arduino’s commands) detected by one of the digital inputs of the mentioned data acquisition card.

According to the estimated value for this physiological variable, the proposed prototype determines a suitable visual feedback to the user. Figure 3 shows our biofeedback prototype implemented on a breadboard.

3. EXPERIMENTAL RESULTS

The acquisition of a signal to represent a physiological parameter was achieved applying a non-invasive, easy implementation and low cost method, which implies the

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use of an emitter - receptor couple to detect the transmitted light variations. Another possible method to detect light variations using an emitter - receptor couple involves the use of a CNY70 sensor, this sensor is able to detect the light reflection instead the light transmission like the used sensor, and nevertheless the prototype implementation using this specific sensor did not produce the expected results. Instead, we utilize an infrared LED – 950 nm, which, in spite of being simpler, reached a better performance for this application. Also, it is a non-expensive device fulfilling the low-cost condition.

We proved that it is possible to get a better output signal quality with the application of an appropriate treatment to the sensed signal through the filtering and amplification stages, making it easier to handle the signal for a proper calculation of the desired parameter, that is the heart rate. The selection of visual feedback given to the user was made depending on the calculated heart rate. Particularly, the range or level of heart rate variability is visually depicted by meaningful frames on the display, as seen in Figure 4. Such frames resemble faces, which correspond to the different moods or heart rate levels.

The following are the established ranges for the visual feedback selection:

- **Low:** Less than 60 beats per minute. The visual feedback displayed corresponds to Figure 3(a).
- **Medium-low:** From 60 to 80 beats per minute. The visual feedback displayed corresponds to Figure 3(b).
- **Medium-high:** From 80 to 100 beats per minute. The visual feedback displayed corresponds to Figure 3(c).
- **High:** More than 100 beats per minute. The visual feedback displayed corresponds to Figure 3(d).

The ranges for the heart rate could be associated with states of bradycardia, normal, exaltation and tachycardia respectively.

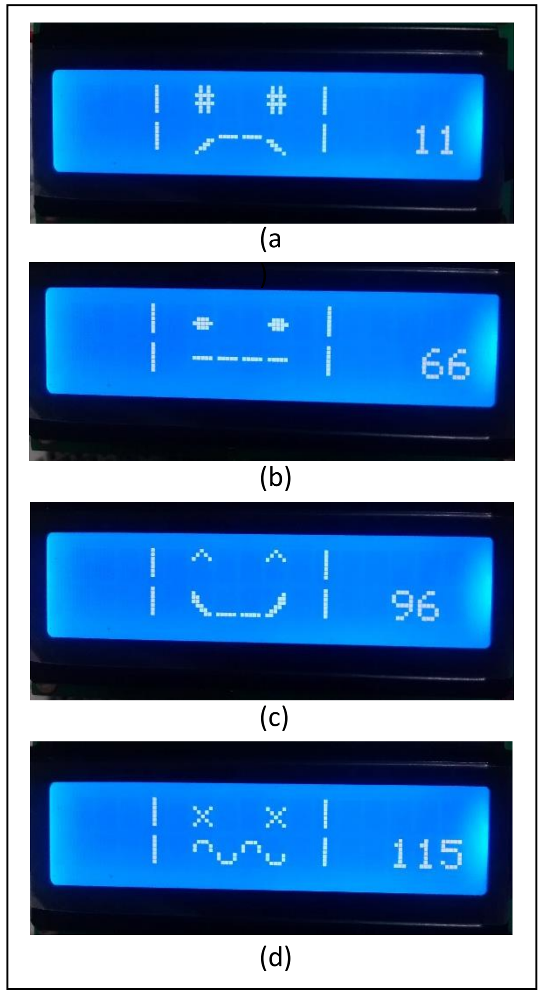

Figure 4: Visual feedback using mood faces for low (4(a)), medium low (4(b)), medium-high (4(c)) and high (4(d)) level of heart rate.

The aforementioned ranges were established in order to carry out an initial test phase, these could change depending of several characteristics proper of the user such as age, physical condition, gender, among others for this is necessary to design a prototype - therapist interface, so these ranges may be established by the specialist who perform the therapy, then it can give parameters which consider convenient. In the same way the specialist will have access to the modification of the criteria selection for visual feedback to avoid limitations in the therapy application.

Additionally, it should be clarified that the proposed prototype is presented as a diagnostic support tool for the implementation of biofeedback therapy, not as equipment to treat specific disorders or diseases without supervision of a therapist.

4. CONCLUSIONS AND FUTURE WORK

As a result of this research, we develop a basic prototype for biofeedback applications using the heart frequency as a physiological variable. Our design is a portable prototype costing about 70 US dollars. Price is significantly low, given that actual commercial devices for biofeedback applications are priced at around 4000 US dollars.

As a future work, more sophisticated acquisition stages are to be designed in relation to high performance, ergonomics and cost of implementation. Also, we are aiming at studying other biofeedback techniques associated with the use of physiological variables related to the brain activity or to the breathing.

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