

EKG Through Sound-Card

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Abstract

This paper describes a cheapest method to realise a compact monitoring EKG system, using a electronic device and software. The device will be able to increase biosignals and forward them to the PC through the sound-card. It will also have software specialized in taking over the received signals and displaying them on the screen of the PC.

Keywords: electrocardiograph, EKG, sound-card, heart monitoring

1. Introduction

Our purpose is to realize a cheap and compact monitoring EKG system with applications in the medical system. The paper is based on [3-17] regarding the medical, electronic and programming aspects.

Recent studies have highlighted the fact that heart diseases have become the main factor of mortality. This has led to an increasing demand for monitoring equipment and for certain procedures of processing heart signals. The electrocardiograph is the device which receives the electric biological signal produced by the heart, amplifies it and forwards it to an analogic or digital shape to be further processed. The market demands are now directed towards the mobility of these devices, an increasingly better data processing and a lower energy consumption. Modern EKG devices (Electro-Cardio-Graph) are equipped with a printer, digital processing, PC communication or Internet links, or with mobile telecommunication networks.

Although the concept of EKG is not new, the main feature of this project lies in offering a simple, compact, low energy consumption, financially attractive product which meets with the medical health standards of protection and operability. The device will be able to increase biosignals and forward them to the PC through the sound-card. It will also have software dedicated to taking over the received signals and displaying them on the screen of the PC.

1. The Electrocardiogram

In August 1887, the British physiologist August D. Wallter published the first studies of human electrocardiography, performed with a capillary electrometer. In 1889, he experimentally demonstrated these human electrocardiography studies on the occasion of the First Congress of Physiology in Bale. Taking part in the demonstration was also the Dutch physiologist Willem Einthoven who, later in 1901, invented a new, more efficient device for EKG recording. Einthoven was awarded the Nobel Prize in 1924 for the invention of the electrocardiograph [2].

The electrocardiogram represents the registration, at the surface of the body, of the cyclic fluctuations of the electric field induced by the rhythmic activity of the heart. This recording is called electrocardiogram (EKG or ECG) and is performed with the help of a device called electrocardiograph. The electrocardiogram reflects the electrical events of cardiac excitation such as heart rate, rhythm and excitation source, pulse propagation and provides information about the anatomical orientation of the heart and the relative size of the heart's compartments. The EKG does not provide information on the heart's mechanical activity (contraction efficiency and blood pumping). The heart can be viewed in terms of a battery, a generator of electric power embedded in a conductive mass (the body). The heart generates an electric field which can be highlighted on the surface of the body through electrodes placed on the skin.

2. Einthoven's Triangle

In terms of power, the trunk and the limbs can be represented as an equilateral triangle with one of the peaks oriented towards the abdomen and the other two towards the shoulders.

Since the human body is a conductive mass, an electrode attached to the arm is the electric equivalent of a connection to the shoulder and an electrode attached to the foot is the equivalent of a connection to the abdomen. Using this principle, we obtain the following three standard bipolar limb derivations (Figure1):

- Derivation I: negative electrode to the right hand and positive electrode to the left hand
- Derivation II: positive electrode to the left foot, negative to the right hand
- Derivation III: positive electrode to the left foot, negative to the left hand.

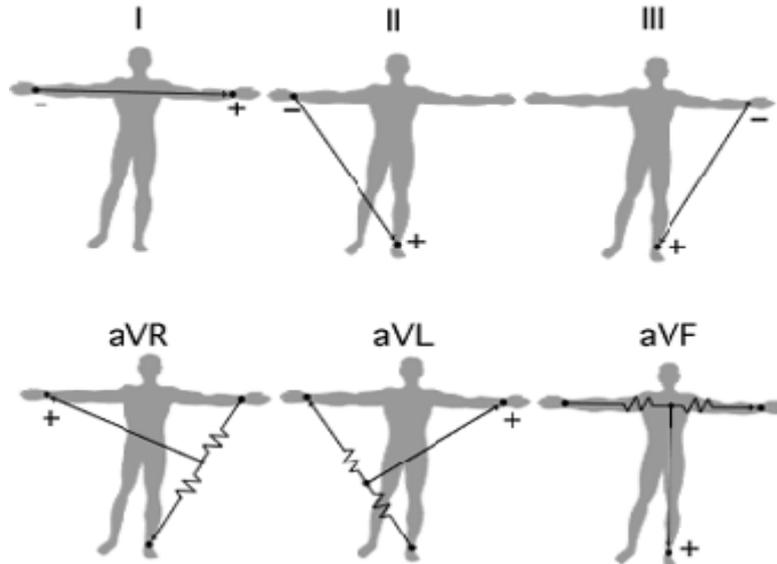


Figure 1. Bipolar limb derivations

To obtain these derivations, the subject is attached to 4 electrodes, one for each limb. By convention, the fourth electrode, the one from the right foot, is used for electrical grounding.

In terms of power, the bipolar limb derivations define a reference point in the middle of the heart. This connection is negative in case of unipolar derivations.

Unipolar limb derivations:

- aVR: plus for the right arm, the negative connection being established in the point from the middle of the heart
- aVL: positive connection for the left arm, the negative connection being established in the point from the middle of the heart
- aVF: positive connection for the left foot, the negative connection being established in the point from the middle of the heart

where: a = augmented; V = unipolar; R, L, F = right, left, foot

Unipolar precordial derivations are six and are obtained by placing positive electrodes on the chest, in standard position. The negative electrode is represented, in this case also, by the electric point at the middle of the heart. The deviations are denoted by the letter V ("unipolar"): V1, V2,V6.

3. The electrocardiograph

The electrocardiograph is composed of EKG amplifier, recorder module and power supply source.

The EKG amplifier takes the signals sent through the electrodes and through a system of a magnetic type of coupling achieved through transformers with the purpose of complete isolation, and forwards them to the digital display module.

The recorder module applies the signal to the preamplifier's non-inverted input and then passes through the limiter which establishes the maximum left or right limits of the stylus, to avoid breaking the recording tape. The power supply of the device contains mainly a convertor with an output transformer and a reaction transformer powered either from a network through a downward transformer followed by a rectifier and filter, or from an accumulator battery.

To comply with the rules of patient protection, the supply for the electrocardiograph's preamplifier is done floatingly according to the grounding null (Figure 2).

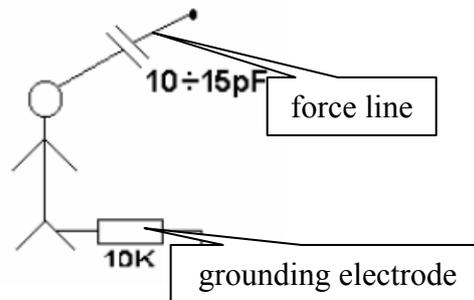


Figure 2. Patient protection in relation to the parasite signals of electric lines

The requirements for the isolation transformer are:

- reduced capacity between windings
- high dielectric stiffness of the insulation

The electrocardiograph should measure electric signals with amplitudes of about 1mV, but should simultaneously ensure a good rejection of the network hum at the input of the preamplifier as a common mode noise of 50Hz. The ratio of minimum common-mode rejection can be calculated on the basis of an equivalent scheme.

The value of the coupling capacity between the patient's body and the supply network is approximately 10-15 pF. Through this capacity and the patient, a current of approximately 1μA and with the frequency of 50 Hz closes towards the mass. This current will determine an effective tension of approximately 10 mV on the grounding electrode's equivalent resistance in contact with the patient. This sound tension will occur at the two inputs of the amplifier as a value of common-mode. To reduce the influence of this noise, one needs to find out the value of the ratio of the common mode rejection so that the output noise may represent 1% of the EKG signal. The ratio of the CMRR common-mode rejection will be, in this case, calculated by the relation (1):

$$CMRR = \frac{10mV_{ef}}{1mV_{vv} * 0,01} = 69dB \quad (1)$$

By using an isolated preamplifier, the grounding of the patient is done through a value capacity of 100-150 pF. The common mode noise tension determined by this capacity will have a value of approximately 20 Vef. The common mode rejection ratio will have to be increased up to 20 Vef / 0,01mVvv, which is 135 dB. For this type of electrocardiograph, a careful design of the preamplifier is required.

The electrodes which can be used by the electrocardiograph are of several types, according to their shape: flat, with suction, or flexible single-use. The value of the contact impedance between the electrodes and the skin can reach 10K, so that an amplifier input impedance of 1M is appropriate. In practice, due to the fact that the contact impedances of the two electrodes are not equal, and to obtain a common mode rejection ration of 80 dB, one should choose a preamplifier input impedance of 100M.

The disturbing electrical signals which are superimposed to the EKG signal are those coming from the muscles (EMG) whose spectrum of frequency exceeds that of the EKG. This interference can be eliminated with a low-pass filter.

To establish the diagnosis, the EKG signal must be measured in a frequency band of 100 Hz, while a band of 40 Hz is sufficient for monitoring. The spectral component of interest is given by the lowest frequency from the EKG signal which exceeds 1 Hz, which corresponds to a heart rate of 60 beats per minute. Using a high-pass filter, with a cut-off frequency of 1 Hz, will distort the shape of the signal through the insertion of a phase delay.

In order to maintain the shape of the signal within acceptable limits, a high-pass filter with a cut-off frequency for 3 dB of 0,05 Hz or 0,1 Hz is frequently used.

4. General presentation of the amplifier

The amplifier we have realized has the following parametres:

- Input signal: 2mV for the alternative component and 250mV for the continuous component, produced by the contact between the skin and the electrode
- Band width is between 0.5Hz and 35Hz
- Amplification varies between 200 and 4010

The EKG amplifier is made up of the following functional blocks (see Figure 3):

- instrumentation amplifier
- the circuit which performs the common-mode “right leg” reaction
- high-pass filter
- low-pass filter
- output amplifier
- power supply block

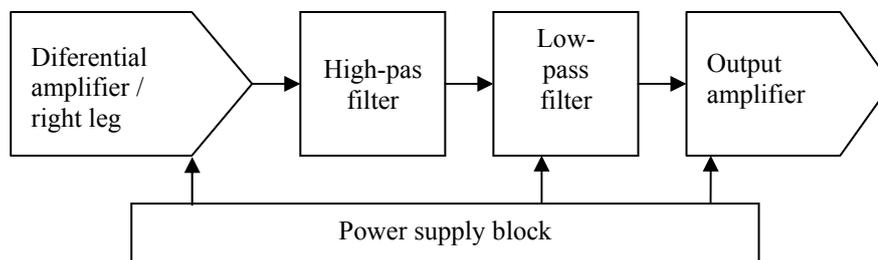


Figure 3. The block diagram of the EKG amplifier

4.1. The circuit which performs the common-mode “right leg” reaction

The common mode “right leg” type of system is an alternative to connecting the patient to the ground, in many modern electrocardiographs.

The operational amplifier used in the reaction is OP97, a low-power amplifier with an extremely large common-mode rejection (minimum 114dB). The circuit applies to the patient’s right foot an inverted version of common-mode interference with the purpose of cancelling the total interference. The operational amplifier has a common-mode rejection of $91 \left(\frac{R_4}{R_2 IIR_3} = \frac{1M\Omega}{11k\Omega} \right)$ and a low-pass cut-off of 160Hz for stability. We have equation (2):

$$f_{-3DB} = \frac{1}{2\pi \times 10k\Omega \times 0.1\mu F} \quad (2)$$

The circuit can also provide protection against accidental electrocution. Rx3 limits the discharged current in case of dangerous tensions between patient and earth.

Component list

IC2=OP97, Rx3=220K, R1=10K, R2,R3=22K, R4=1M, C1=0.1UF

4.2. High-pass filter

It allows signals with frequencies up to 0.05 Hz (cut-off frequency) to pass unaltered while it strongly attenuates those exceeding the cut-off frequency. Figure 4 shows the electronic scheme. This filter adjusts the low impedance exit of the instrumentation amplifier with the high impedance entrance of the high-pass filter.

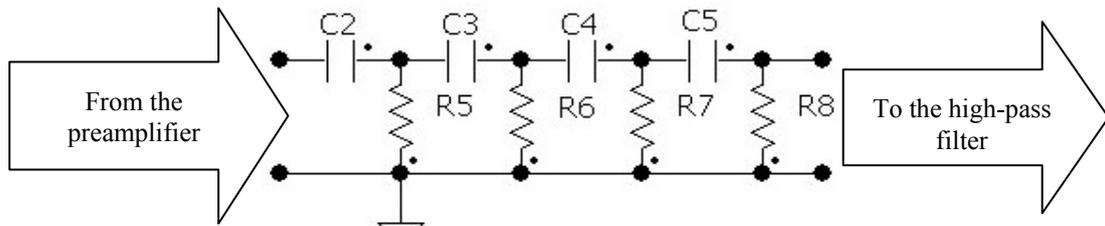


Figure 4. High-pass filter

Electronic component list

C2,C3,C4,C5=2,2 UF, R5,R6,R7,R8=1,5 Mohmi

To calculate the filter, one may use the calculation application found at <http://sim.okawadenshi.jp/en/CRhikeisan.htm> [1] or the following equation (3):

$$f_c = \frac{1}{2\pi RC} \quad (3)$$

4.3 Low-pass filter

The low-pass filter, presented in figure 5, allows signals with frequencies up to 34 Hz (cut-off frequency) to pass unaltered while it strongly attenuates those with frequencies exceeding the cut-off frequency. It is an active filter, of the butterworth sellen-key type which contains one of the four operational amplifiers of the TL084 integrated circuit.

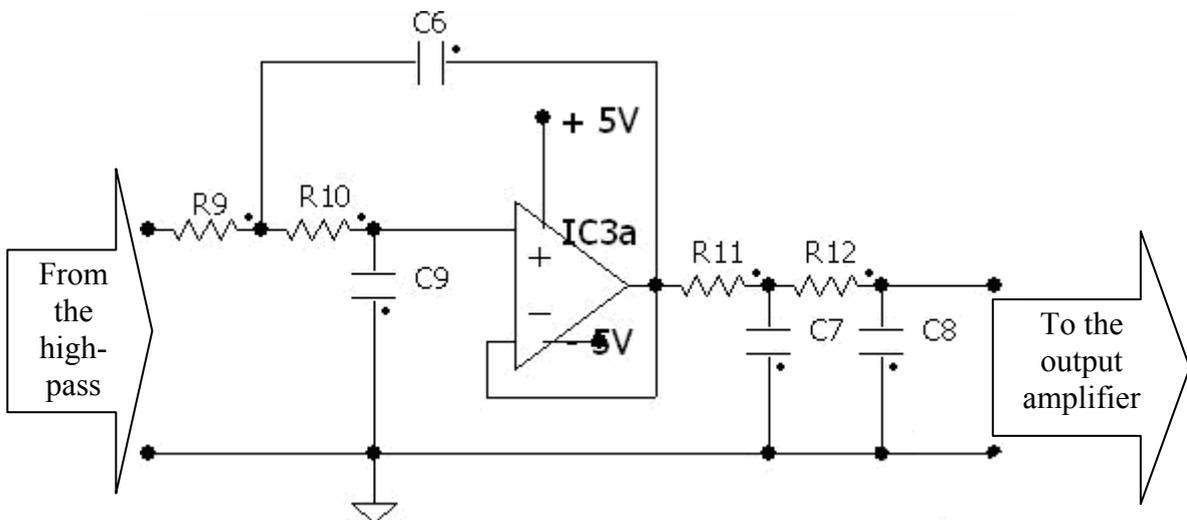


Figure 5. Low-pass filter

The cut-off frequency can be calculated by using the simulator at <http://sim.okawa-denshi.jp/en/CRhikeisan.htm> or the following equation (4):

$$f_c = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}} \quad (4)$$

Component list

IC3a=TL084, C6,C9,C7,C8=0,047UF, R9,R10=100K, R11,R12=1K

TL084 Technical specifications (Figure 6):

Low-power, small input current, the circuit has protection against short-circuiting. Also, distortions are of the 0.003% Typ. The input impedance is high due to the JFET input. The circuit contains four operational amplifiers with JFET input.

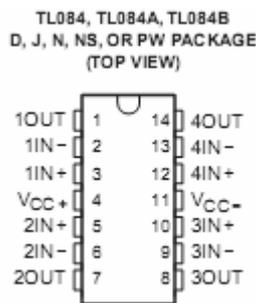


Figure 6. The capsule of the integrated TL084 circuit

4.4. The output amplifier

The electronic scheme of the output amplifier shown in Figure 7 contains one of the operational amplifiers found in the integrated TL084 circuit used in the low-pass filter. With the help of the potentiometer P1 one can adjust the amplification level from 10 to 210.

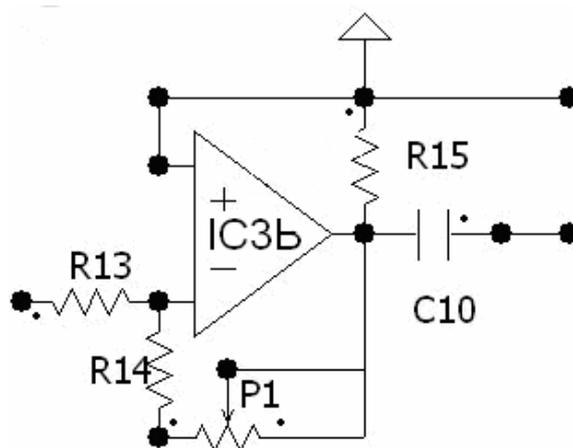


Figure 7. Output amplifier

The amplification of the circuit can be calculated using the following formula (5):

$$G = R_a / R_b \quad (5)$$

Component list

IC3b=TL084, R13=1K

R14=10K, R15=20K
 P1=200K, C10=2.2UF

4.5. The power supply block

The power supply block shown in Figure 8 supplies the circuits of the EKG amplifier with the tension required for proper functioning. Supplying the fitting is done with a dual tension obtained from two 9V batteries. Since they work on bipolar input signals, integrated circuits must be supplied from a source of dual tension of $\pm 5V$ provided by the regulatory integrated circuits IC4 and IC5, which lower the tension of $\pm 9V$. The condensers C11,C12,C13,C14 clear the supplying circuit.

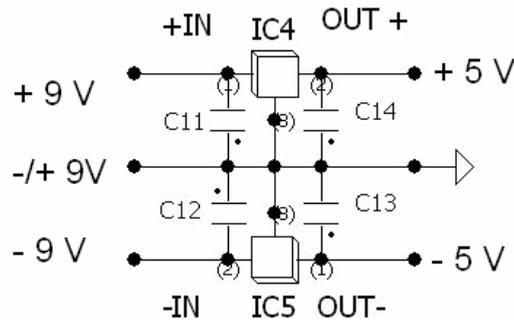


Figure 8. The power supply block

Component list

IC4=7805, IC5=7905, C11,C12,C13,C14=0,1UF

7805 Technical specifications

Output tensions of +5V, Maximum output current 1,5 A, Protection against short-circuit

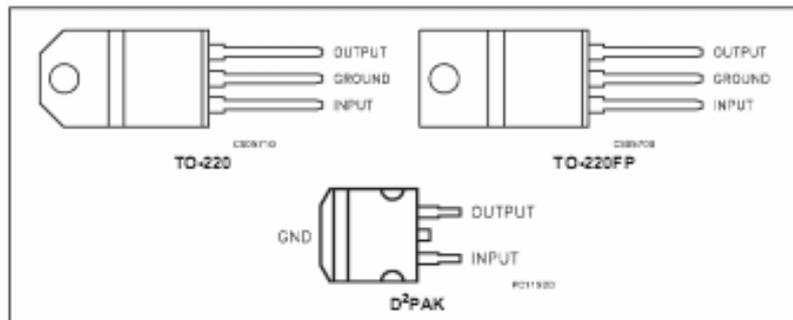


Figure 9. The 7805 integrated circuit

7905 Technical specifications

Output tension -5V; Output maximum current 1,5 A; Protection against short-circuit

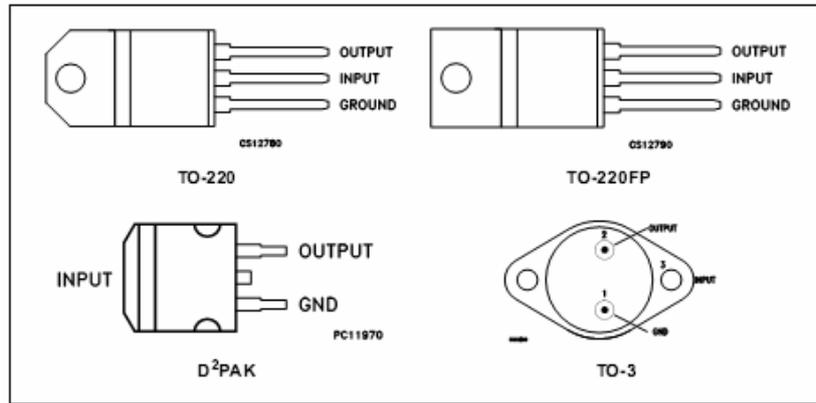


Figure 10. The 7905 integrated circuit

4.6. Practical achievement

The electronic circuit was assembled on two doubly copper plated test plates which were placed on a chassis made up of a hard plastic plate (Figure 11). The preamplifier was armoured with an iron plate to reduce the influence of the electric network. The entire assembly was introduced in a plastic box specially designed for electronic fittings. The linking cables of the three electrodes are also armoured and connect to the electronic module via RCA sockets.



Figure 11. Practical realization of the EKG amplifier

The connection with the computer is done through an armoured cable equipped with a jack socket at the microphone's input into the sound card.

The electrodes used are self-adhesive, single-use and were ordered from a distributor in medical equipment.

5. Graphical representation soft for the EKG signal

In the current chapter we shall describe a type of software for monitoring a patient's (human subject) heart activity. Through the sound-card (the microphone socket), the program takes audio signals amplified by the electronic fitting presented in the last chapter and displays them graphically on the screen of the computer.

We shall first present the way in which the program (called *Heart Monitor*) is used, together with the electronic fitting, and then we shall present and explain the instructions for the program.

5.1. Use of the EKG program

After installing the software (from the Setup.exe file from the delivery CD), you run it from the *Start menu* → *Programs* → *Heart Monitor (group)* → *Heart Monitor (program)*. The program works on the Windows XP operating system, but also on previous versions of 32 de bytes, it requires a minimum hard-disk free space (1 Mo), a sound-card of 16 bytes (minimum), with microphone socket, and a video-card with a resolution of at least 800x600 pixels.

After starting the program, the electronic equipment will be set up on a fixed support (a table), and the silvery jack will be plugged into the sound-card, in the microphone socket (Figure 12). Then, the three electrodes will be attached to the patient. The patient will lie down on a plane surface (a bed or a stretcher for consultations), relaxed, with the arms stretched and the head towards the right (see Figure 13).



Figure 12. Plug-ins and sockets of the sound-card

The positive electrode will be applied on the patient's chest, in the direction of the heart (Figure 14), the negative electrode on the right forearm (Figure 15), and the mass electrode on the calf of the right leg (Figure 16).



Figure 13. The correct position of the patient's body during heart activity monitorization



Figure 14. Attaching the electrode in the direction of the heart



Figure 15. Attaching the electrode to the right hand



Figure 16. Attaching the electrode to the right leg

The electrodes will be labelled, so that their installation may be correctly done. For a reduced resistance to the connection between the electrodes and the skin, the electrodes will be moistened with a piece of cotton soaked in sodium chlorate, with a concentration of 15-25% (Figure 17 left). One can also use a special EKG gel which can be ordered from online pharmacies (Figure 17 right).



Figure 17. NaCl (20%) solution and EKG gel

After that, the patient will be asked to wait for a few minutes, during which he will relax, and we will adjust the amplitude of the input signal into the computer's sound-card, through the microphone socket. For this, we will use the program Sound Control from *Start* → *Programs* → *Accessories* → *Entertainment* → *Sound Control* (Figure 18).

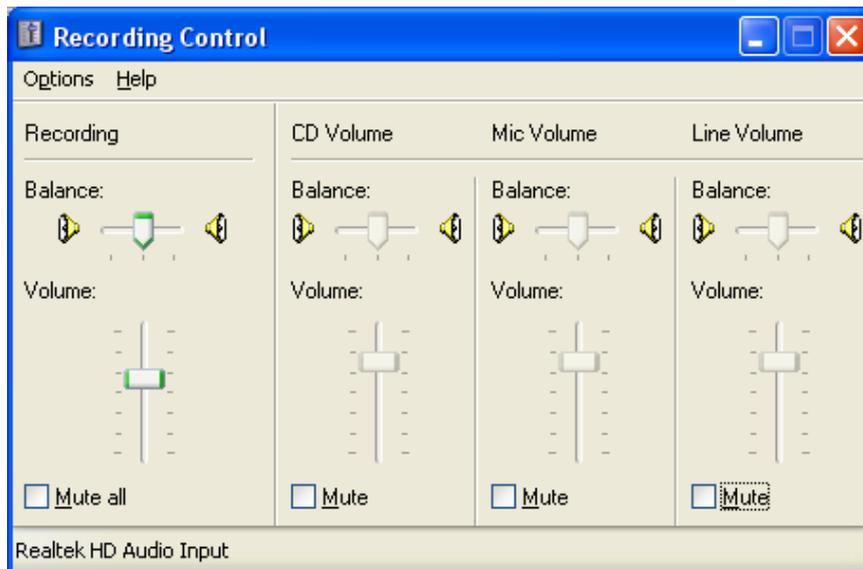


Figure 18. Adjusting the signal input through the microphone socket

As soon as all the elements of the electronic fitting have been fettled, the “Start” button from the *Heart Monitor* program will be pressed. For auto configuration, one can check the “Auto configuration” option. Autoconfiguration means a level margin where the tops of a sine curve are read, so that the program will display the number of heart beats per minute. One can also opt to manually choose a level, which will be entered in the corresponding field, after unchecking the “Auto configuration” option. In the field labelled with “Time (sec)” one should introduce the number of seconds which represents the period in which the signal is represented graphically between the left and right limits of the representation zones (see Figure 19).

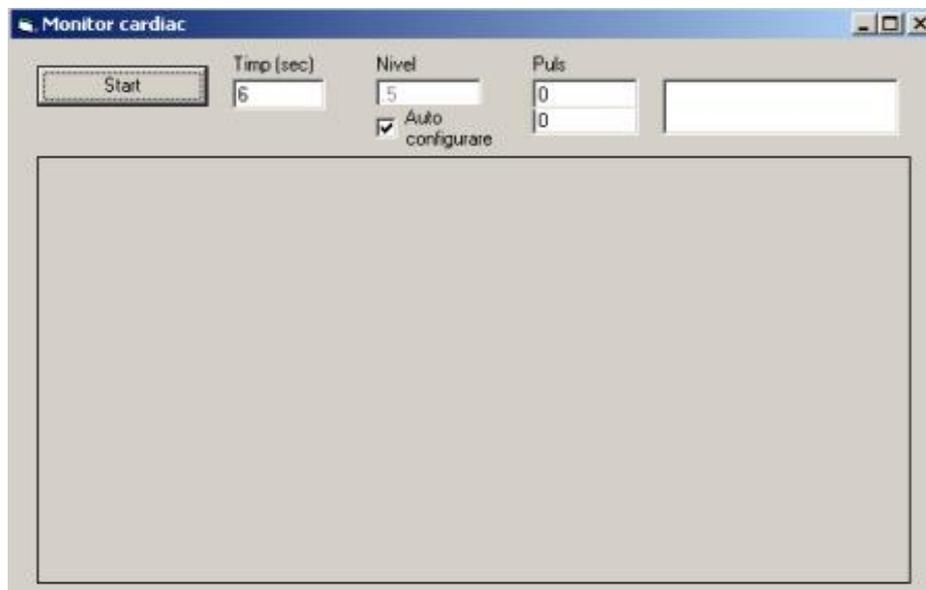


Figure 19. The initial interface of the *Heart Monitor* software

In case the number of seconds (Figure 9 shows 10 seconds) increases, then the representation of the electrocardiogram will be coarser and if the number of seconds decreases then the representation will be more accurate (Figure 20).

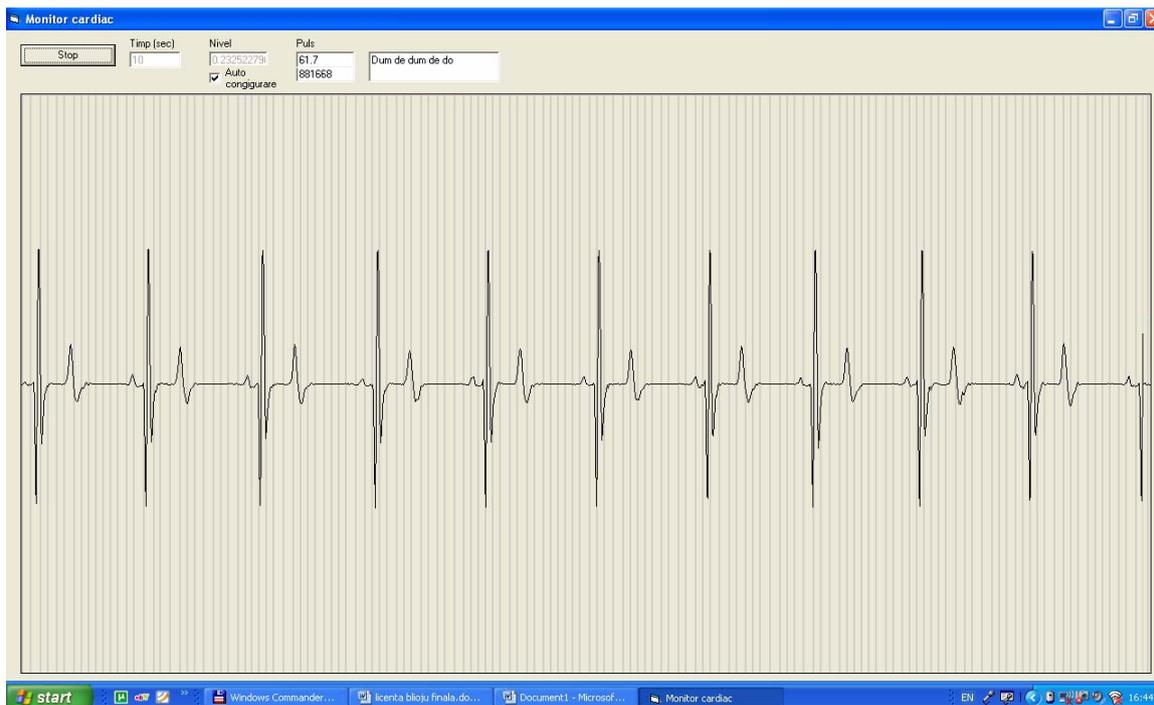


Figure 20. Coarse electrocardiogram



Figure 21. Accurate electrocardiogram

Figure 22 shows our patient's electrocardiogram (C.B., female, aged 21, clinically healthy, blood pressure 10/7, blood group A2).

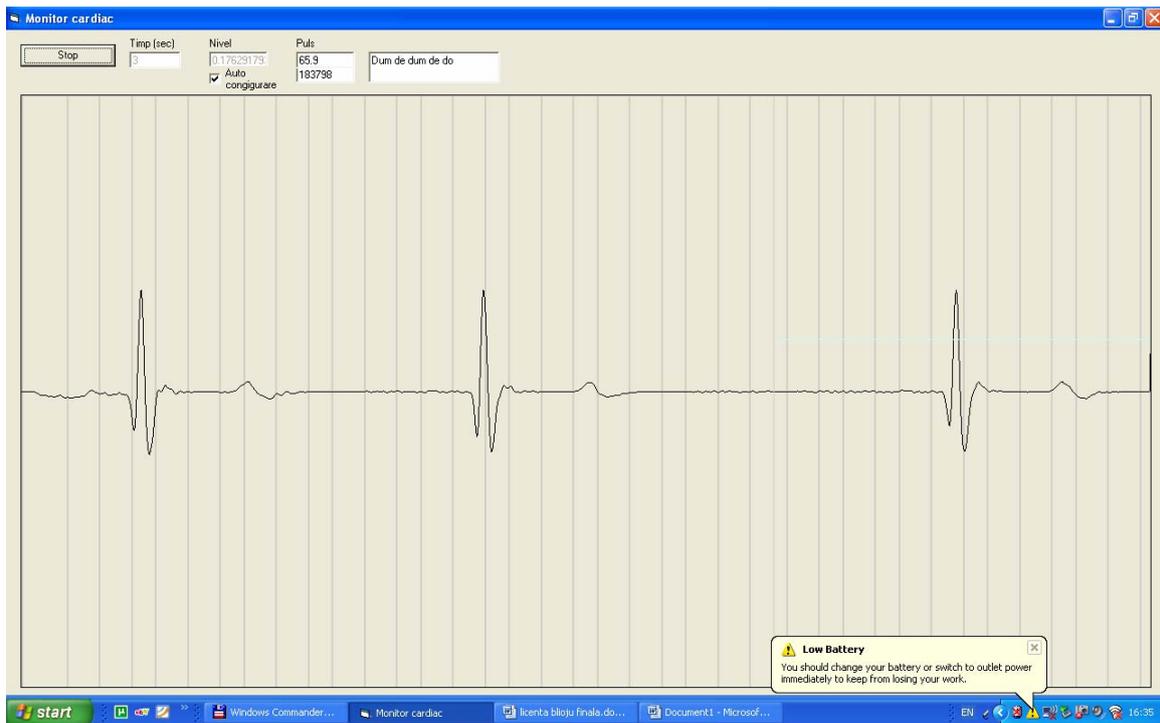


Figure 22. Example of electrocardiogram

To properly represent the bioelectrical signal, the sources of electromagnetic noise will be eliminated (medical, electric, electronic equipment, GSM devices, radios and TVs, computers, etc.), and the patient will stay still. For paper printing, one may press the Print Screen key and then the graphical representation can be copied into a program (e.g. Word, Paint) and printed on graph paper. For the interpretation of results and the establishment of a diagnosis, a cardiologist will be appealed to.

In case the patient's pulse is zero, the text field will display the message "Dead patient. Call on a priest", and if the pulse is higher than 50, then the message displayed will be "Dum de dum de do". Also, if the pulse is higher than 110, the message displayed will be "Take exercise!", and for a pulse higher than 300, the message "Pulse is too high. Make sure the electrodes are properly connected" will appear.

5.2. Experiments and Technical Data

After the experiments that we have carried out on a number of 50 subjects (25 men and 25 women), aged between 14 and 60, healthy as well as suffering from various heart diseases, the obtained results were comparable to those obtained by a professional electrocardiograph. The cost for the entire monitoring system we have realised rises to 2000 Euros (500 Euros for the computer, 500 Euros for the licensed software (Windows XP and Visual Basic 6), 500 Euros for the components of the electronic fitting, 500 Euros for the labour) as compared to the cost of an electrocardiograph which costs 20.000 Euros.

Our program was realised and tested on a Compaq laptop having the following features:

- Processor - P 3 la 1000 Mhz
- RAM - 512 Mb
- HD -19 Gb
- Video-card -Radeon 7500 AGP

For software development we have used the Visual Basic 6.0 visual programming environment because it allows both interactions with the video-card as well as easy achievement of graphic user interfaces (GUI).

We have made a module called Fucntions.bas which contains the functions specialized in accessing the sound device (sound-card). For this purpose, we have defined a few constants and

then we have implemented the `waveInAddBuffer` function, on the basis of the dynamic system library `winmm.dll` (Windows Multimedia), which takes over the sound signal. We have also written the opening and closing functions of the sound entrance (`waveInOpen`, `waveInClose`), as well as other functions required by direct access to the audio signal from the microphone. These were achieved with the help of the "Constant Thought RecordScope v1.0" software.

6. Conclusions and future works

The objectives aimed at have been reached. An electronic monitoring system for EKG signals was obtained at a low cost, which can be used both for people and animals. Although sound-cards have certain limitations in amplifying low frequencies, the EKG monitoring system is worth further development.

We will develop a complex system for electronic stimulation of the temporal lobes of the brain, in order to generate modification in the emotions of a young person. This system will use the EKG device we described above. The EKG will monitor the heart activity, to see how the subject will act at the temporal lobes stimulation.

7. References

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