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CONTACTLESS ECG SCANNING DEVICE HARDWARE DESIGN PROPOSAL

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Abstract: In this paper proposals on construction of the contactless ECG scanning system hardware are described. The philosophy of the system is based on the idea of creating a simple-to-be-worn dress that includes capacitive ECG sensors the outputs of which are transferred to the A/D converter of a processing device. Contemporary technologies enable sewing of the sensors as well as the connecting wires into the dress. The processing device receives three analogous signals corresponding to the potential differences sensed on the body of the measured person. The paper is focused on the problem of getting and transmitting this signal to the processing device.

Keywords: ECG, Contactless, Capacitive Sensors, Signal Processing

1. INTRODUCTION

Currently, ECG scanning systems are undergoing a small revolution. New methods of ECG scanning have been introduced recently, being less bothersome to the monitored person. One of these methods consists in application of contactless sensors that work on the basis of a capacitive coupling to the monitored body. Several approaches have been introduced in literature, for example [6], [7], [8]. The authors of [6] suggested employing of digital connection among the sensors displaced around the measured body together with wireless technologies transferring the scanned data to the processing unit. The authors of [7] proved the possibility of scanning the ECG with only two capacitive sensors, creating one lead that is applied between the shoulder blades of the measured person. In [8] there is a complex description of a capacitive ECG scanning system and a discussion on the results achieved, but no information on capacitive sensors is provided. The authors of this paper would like, based on the knowledge gained in [6], to suggest a hardware concept of a capacitive ECG scanning system that is implemented in a dress of the scanned person and connecting to the processing device that may also be worn by the person or can be dislocated near to her or him.

2. ESSENTIALS OF THE ECG THEORY

The ECG (electrocardiogram) [1], [2] represents a history of potential differences on surface of the body. The difference of electric potentials is an electric voltage (1) thus ECG provides information on the heart function as explained below.

$$U = \varphi_2 - \varphi_1. \tag{1}$$

The heart is an absolutely indispensable part of human-beings and animals for its function to provide supplies of blood to all parts of organism (thereby oxygen is delivered to the organism). It can be said that the heart behaves like a pump. Operation of this pump in the form of the heart and its activities is driven by electric current passing over myocardic cells. The electric current stimulates the heart thus its contraction is triggered. The “pumping” process of the heart is ensured by two movements of heart muscle termed as systole and diastole. Systole is a heart movement when the heart (or parts of the heart termed as chamber and atrium) contracts in order to pump blood up within blood recirculation. Diastole is an opposite movement. In this case the heart (parts termed as chambers) relaxes and an expansion is processing. Shortly, blood fills the heart. These two movements are subsequently alternated.

The electric current administers two tasks. The first one is a task when electric current ensures triggering of a systole. The second task which is no less important is driving of correct heart activity while systole occurs. In the living organisms the impulse of electric current is originated in sino-atrial node of the heart which can be considered as internal biological pacemaker and its abilities are a result of electrochemical backgrounds of cellular processes.

Propagation of electrical current (or voltage) can be measured as a difference of electric potentials on the surface of the body. As the devices for measuring electric potentials on the body the electrodes which are connected to the lead systems [2] are used. The lead system represents a way of positioning of electrodes thus measured signal is significantly influenced by used lead system. There is a large amount of lead systems which vary by number of leads thus electrode placement positions. If it is talked about lead, it is necessary to mention a form of lead. Simply, each lead [2] consists of three electrodes. Two of them serve for electric potential measurement. The last one represents the ground.

In this research it is necessary to consider selection of lead system which means a compromise between number of leads (electrodes) and information provided by them. It can be said that higher number of leads has positive effect on information obtained by measurement. As well as the placement of electrodes within lead systems can provide a view of electric current propagation in heart tissues in different body planes.

The 12-lead system [2] can be considered as a clinical standard for ECG measurements. This lead system is comprised of 10 electrodes. There are three bipolar limb leads (3 electrodes) and nine unipolar leads. These are 3 augmented Goldberg leads [2] (3 electrodes shared with bipolar limb leads) and 6 chest leads [2] (6 electrodes placed in thoracic area). The last electrode is shared with other leads and represents the ground. There are three disadvantages of this lead system. The first one is a high number of leads (electrodes). The second one is an impossibility of measure information provided by all leads simultaneously (because some electrodes are shared with different leads). The last disadvantage is a placement of electrodes in limbs. This disadvantage can disappear when Mason-Likar [2] modification is used. The modification enables a relocation of limb electrodes to the torso (shoulders and lower abdomen). However other disadvantages of 12-lead systems remain.

Certain possibilities can be seen in derived 12-lead systems where the number of leads is reduced. One of those lead systems is the EASI lead system [2]. This system is based on Frank's lead system [2]. As well as the Frank's lead systems, the EASI lead system is orthogonal. It means that provided information by the EASI lead systems is a projection of electric current (or voltage) propagation in frontal, sagittal and transversal plane. There are three leads and five electrodes. These electrodes are placed on anatomically significant locations thus the position of electrodes can be easily determined (contrary to 12-lead system where the placement of thoracic electrodes especially is rather complex). In the EASI lead system the positions of electrodes is: lower sternum (E), 5th intercostal space in left mid-axillary line (A), manubrium (S), 5th intercostal space in right mid-axillary line (I). The last electrode can be placed anywhere on torso (e.g. right lower abdomen) and represents the ground. On the basis of signal measured by these three leads, the information provided by full 12-lead system can be derived. This is ensured by simple linear combinations of values of measured electric voltage and empirically-found coefficients (e.g. in the form of Dower matrix [2]).

In the case of EASI lead system, equation (1) can be transcribed to the following equation system [2]:

$$\begin{aligned} U_X &= \varphi_A - \varphi_I \\ U_Y &= \varphi_E - \varphi_S \\ U_Z &= \varphi_A - \varphi_S \end{aligned} \tag{2}$$

The mentioned derivation of information can be generally expressed as:

$$U_{derived} = aU_x + bU_y + cU_z, \tag{3}$$

where a, b, c are empirically obtained coefficients.

Although derived information can be slightly different and inaccurate than the real information provided by 12-lead system, it is possible to obtain continuous measured values of all leads together. Fig. 1 depicts comparison of the ECG signals. This first one is really-measured information on thoracic V2 lead (part of e.g. 12-lead system). The second signal represents same information on V2 lead which is derived from Frank's lead system. The derivation was computed by Dower coefficients [2]. The information on 12-lead system as well as Frank's lead system can be found in the PTB Diagnostic ECG Database [3, 5] which is available as part of PhysioNet Library [4].

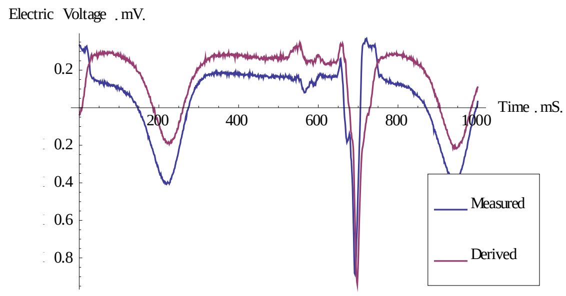

Fig. 1 – Comparison of measured and derived information on V2 lead.

After consideration of all advantages and disadvantages of the EASI lead system described above, this system was selected as the suitable one for this research.

3. CAPACITIVE SENSORS PRINCIPLE

As stated above, not only physical connection of the leads to the measured person's skin but also other principles may be employed to scan the ECG signal. One of such unconventional methods is using of capacitive sensors. A draft of a circuit diagram of a capacitive sensor is depicted in Fig. 1. To create one lead, a difference between two captured signals is needed to be gained so two capacitive sensors driving one differential amplifier are needed.

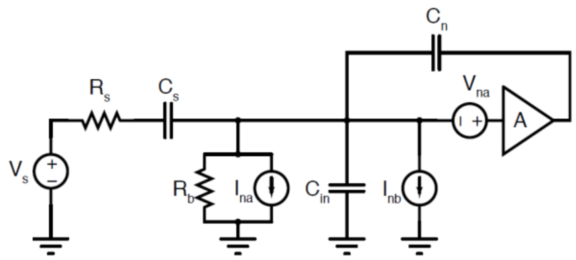

Fig. 2 – Schematic diagram of a capacitive sensor [7]

In Fig. 2 the following devices and phenomenons are depicted: The skin of the body is considered to be a voltage source Vs that produces alternating voltage of small amplitude (≈ 1 mV). The resistor R_s represents the serial resistance of the skin and typically a value of ≈ 1 MΩ can be considered here. The C_s capacitor is the point of our design – it represents the capacitor to be created when an electrode of the ECG sensor is enclosed to the measured body being insulated with a thin layer. Together with the R_b resistor it allows the alternating current from the V_s source to flow through the C_s, creating noticeable voltage potential changes at the input of the amplifier A. Moreover, several parasitic phenomenons can be identified in the figure, as I_{na} corresponding to the input noise current of the amplifier, I_{nb} corresponding to the thermal noise current of the R_b resistor, the V_{na} corresponding to the noise voltage at the input of the amplifier and C_{in} corresponding to the input capacity of the amplifier. The C_{in} together with C_b create a voltage divider that reduces the already low signal voltage at the input of the amplifier. It can be neutralised by employing the capacity C_n providing the positive feedback from the output of the amplifier. The same method is essential to be applied on the active shielding of the sensor which is considered to be necessary for this application. Considering the noise phenomenons, a design of a suitable transformer that would accommodate the high impedances to the optimum input impedance of the amplifier seems to be convenient here, but because for the parameters of the signal (high input impedance, low frequency) the transformer would be quite bulky, this option cannot be taken into account. Low noise electronic devices must be chosen instead.

4. CAPACITIVE SENSORS CONSTRUCTION

In this chapter the physical construction of the capacitive sensors is suggested. It is based on one double-sided PCB which is covered with a shielding cover on one side and insulated with a thin lacquer layer on the second side, as depicted in Fig. 3.

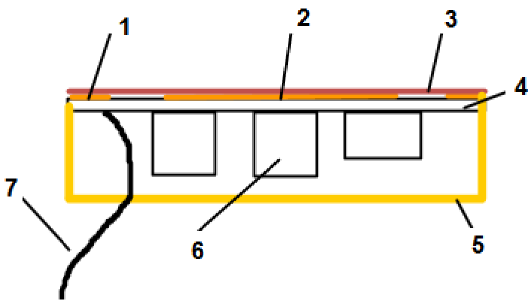

Fig. 3 – Capacitive sensor construction

In Fig.3 the following parts of the capacitive sensor are displayed: 1 – shielding ring around the bottom copper layer on the PCB, 2 – copper layer on the bottom of the PCB acting as a coupling electrode, 3 – insulation lacquer layer, 4 – PCB, 5 – shielding cover that is connected to the shielding ring (1) via several rivets through the PCB, 6 – SMD devices, 7 – cable.

Because for each lead two capacitive sensors are needed to drive a differential amplifier, there is a suggestion to divide the sensors into two types – master and slave. While the slave only consists of an impedance converter designed according to Fig. 2 and the active shielding, the master includes also the differential amplifier and output modulator. The output modulator is employed to improve the interference immunity of the whole system and to reduce the number of wires needed to be implemented in the dress. One master and one slave are connected together creating one lead. For the purpose of the EASI system, three such pairs of sensors are required. The block diagrams of master and slave capacitive sensors are depicted in Fig. 4 and Fig. 5.

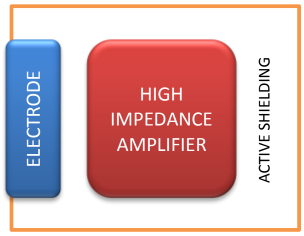

Fig. 4 – Slave capacitive sensor block diagram

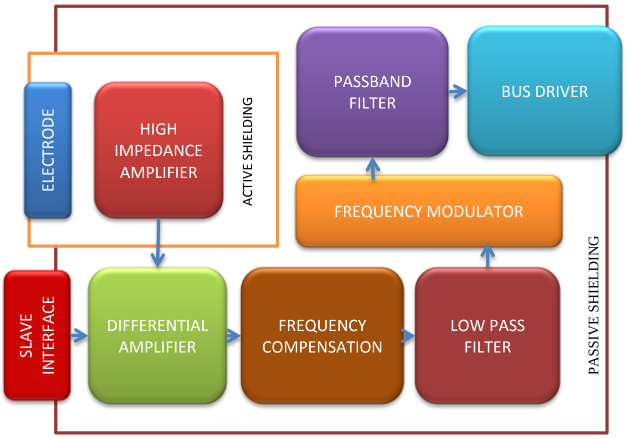

Fig. 5 – Master capacitive sensor block diagram

5. CONTACTLESS SCANNING DEVICE HARDWARE CHAIN

As stated above, three leads are needed to comply with the EASI system specification. Moreover, to cancel the interference signals transmitted to the body of the measured person via capacitive coupling to its neighbourhood an additional active electrode is required, see [7]. In Fig. 6 the chain of the proposed hardware devices needed to create a contactless ECG scanning system is depicted.

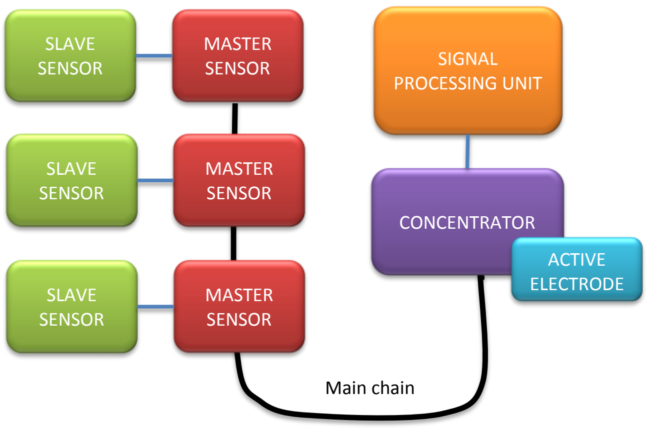

Fig. 6 – Contactless ECG scanning device hardware chain

As can be seen in Fig. 6, three pairs of master/slave sensors are connected with a chain wiring to the concentrator, which transfers the signal to the signal processing unit and also drives the active electrode that can be implemented in the concentrator unit provided the concentrator is also implemented in the dress on the appropriate position (perhaps above the buttock of the measured person).

The slaves are connected to the master sensors via a 4 wire flat cable that is easily implementable into the dress. The cable consists of the conductors as follows: 1 – positive power supply + 10V, 2 – signal, 3 – GND, 4 – negative power supply - 10 V. Inserting the signal wire between the GND and the positive power supply wire being blocked against the GND shall improve the interference immunity. The main chain is also a 4 wire flat cable and it connects all 3 pairs of sensors together with the concentrator. The connection of the wires is also the same – positive power supply, signal wire, GND and negative power supply. All three sensor pairs can send the signal via the single wire as a frequency modulation with the bandwidth of 20 kHz is employed here. Not only the amount of wires is decreased but the interference immunity of the signal wire is improved significantly by this solution.

In Fig. 7 the block diagram of the concentrator can be found.

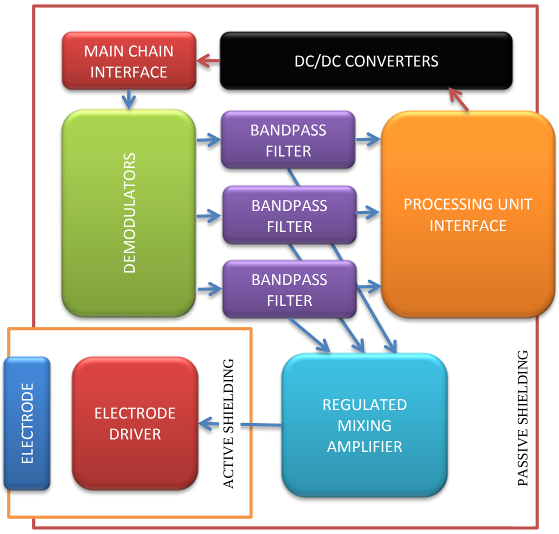

Fig. 7 – Concentrator coupled with the active electrode block diagram

The signal processing unit is supposed to be a simple microcontroller development board equipped with at least three A/D converters. The main task of the contactless ECG sensing system is to capture the changes of the measured person skin potential, amplify it and transfer it to the processing unit. The processing unit then applies the pertinent phase corrections on the particular channels (leads) as the frequency modulation may cause phase distortion of the signal and when corrected, the signal is being processed by digital algorithms within this unit. The only requirement on the processing unit is that it must be capable of delivering the power supply to the DC/DC converters implemented in the Concentrator that creates symmetrical voltage to better supply the operational amplifiers implemented in the master/slave capacitive sensors.

All the blocks depicted in Fig. 7 except the processing unit are supposed to be implemented in the dress. The dress itself can be composed as a shirt or an appropriate belt or another type of the dress that is easy to be applied on the measured person. The displacement of the sensors must comply with the EASI standard. It is necessary the sensors did not move against the skin when the measurement is running.

6. CONCLUSION

The aim of this paper is focused on presentation of the idea of the hardware conception of the system that enables the user to easily and comfortably scan the ECG signal by employing capacitive coupling of the sensors implemented within a dress. The output of this hardware system consists of three analogous signals that is processed digitally in any conventional signal processing unit equipped with at least three A/D converters. Each of the blocks of the system consists of several electrical circuits implementable also into the dress together with the necessary wiring that has been restricted to minimum. These electrical circuits are subject to further development and testing in the framework of the project “21st century fireworker”.

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