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Mobile R-Wave Detection System Powered By A Thermoelectric Generator

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Abstract— **In modern medicine, monitoring devices for mobile application are using rechargeable power supplies. A new concept refers to energy scavenging techniques using heat emission from human body. This project deals with the development of a prototype and the feasibility study of a thermal harvester.**

A thermoelectric generator enables the device to work self-sufficient on temperature gradients between skin and ambient conditions. This developed energy harvesting system converts human body heat into electrical energy. In combination with ultra-low-power components autonomous operation should be possible. The system should enable an R-wave detection circuitry. If the temperature gradient is high enough, there is supposed to be no lack of power as in case of ordinary battery systems.

A system combining thermal energy harvesting and signal processing is developed. To show the functions of the energy harvester corresponding measurements are performed. The signal processing unit is set up but not evaluated in concrete measurements.

Keywords— **Thermal Energy Harvesting, R-Wave-Detection, Thermoelectric Generator, TEG**

1 INTRODUCTION

A major drawback of the current generation of mobile biosignal-monitoring systems is the power supply. Common options are based on rechargeable batteries.

Due to external charging processes continuous monitoring of vital parameters is limited.

1.1 Continuous Monitoring

Some vital parameters such as heart rate, pulse in rate and quality, oxygen saturation and blood pressure must be observed continuously in case of high risk patients. In view of continuous mobile observation reliable power supply is essential.

A power supply based on energy harvesting, for example by utilizing energy from temperature gradients, allows an autonomous measurement environment. The human body continuously radiates heat from an average body surface area of $1.7\,\mathrm{m}^2$. A thermoelectric generator (TEG) is attached to the body acquiring just a fraction of the $100\,\mathrm{W}$ thermal energy emitted by the total skin surface [8]. Successive measurements of vital functions will be permanently available without any need of external recharging or replacement of components.

1.2 Aim of this Work

The aim of this work is the development of a mobile R-wave detection system using human body heat as a power source. The human body heat can be seen as an infinite source of energy throughout the entire life cycle [11]. This work consists of two main tasks (I) and (II) (Figure 1).

The first task deals with the conversion of body heat into a storable form of energy (I Harvester). Due to low temperature gradients the TEG output voltage is very low as well. This is subsequently boosted with the aid of a DC/DC converter and stored in a capacitor or battery. It is important to maximize the power of the TEG by minimizing the power dissipation at the same time [7].

The second part of the project focuses on using the saved energy to drive the R-wave detector (II Signal Processing). The detection circuitry is based on an instrumentation amplifier followed by a microcontroller. The calculated heart rate is displayed on a liquid crystal display (LCD) [3].

1.3 Structure

The structure of the paper is as follows. Section 2 provides a summary of necessary foundations in terms of methodology of thermal energy harvesting. There are also technical fundamentals and principles explained that contribute to the understanding of this work. The underlying concept is described and discussed in detail. Following Section 3 presents the results of the test series. Finally, Section 4 draws the main conclusions of this paper and presents possible improvements and prospects of the project.

2 MATERIALS AND METHODS

The developed concept is based on two separate electronic circuitries. This deliberate separation allows the independent development of the two devices (Figure 1).

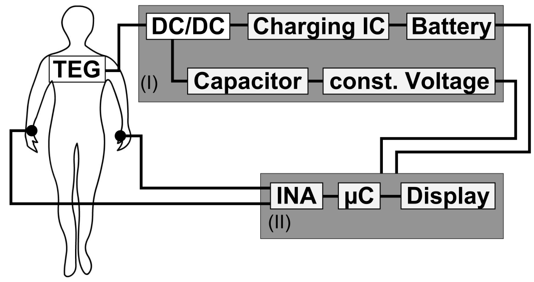

Figure 1: Conception overview showing independent devices of this project - (I) Harvester - (II) Signal Processing

2.1 Setup of the Apparatus

The selected TEG 127-200-28 [10] has a contacting surface of 30 mm by 30 mm. The thermopower is declared as $\alpha = 0.056\,V/K$ and the thermal conductivity is specified with $\kappa = 0.180\,W/K$. The energy harvesting devices rely on integrated components by Linear Technology [5]. The auto-polarity DC/DC converter (LTC3109) works with small input voltages of $V_{in} = \pm 30\,\mathrm{mV}$. This voltage is transformed and conveyed either to the intelligent battery-charging-circuit (LTC4070) with an additional Lithium-Ion (Li-Ion) battery or to the super-capacitor (Goldcap). A simple jumper allows switching between the two charging operation modes. The capacitor's nominal voltage is specified with $V_{nominal} = 5.5\,\mathrm{V}$ at a capacity of $C = 1\,\mathrm{F}$. The saved energy needs to be regulated to a constant level of $V_{reg.} = 3.3\,\mathrm{V}$ (LT3009-3.3). The selected battery is a rechargeable Li-Ion battery that provides a nominal voltage of $V_{nominal} = 3.6\,\mathrm{V}$ at a typical capacity of 120 mAh [1].

The signal processing circuitry utilizes an instrumentation amplifier (INA333) for the preprocessing (filtering, differentiation, amplification) [9]. The calculation of the heart rate is performed by the microcontroller (MSP430AFE221) [9]. Furthermore, the heart rate is forwarded to a LCD display (EA DOGM163W-A) [2]. In order to reduce additional circuitry all components are powered by $V_{cc} = 3.3\,\mathrm{V}$ provided by the charging circuitry. In terms of energy saving the instrumentation amplifier as well as the microcontroller is a low-power component. In addition, processing unit is meant to stay in sleep mode while charging is in progress.

2.2 Functionality

As mentioned previously, the project is divided into two independent parts.

The harvester describes the way of energy conversion, transformation and storage. The signal processing unit should use the stored energy of the harvester and calculate the current heart rate from the electrocardiogram (ECG).

Harvester (I)

The TEG exploits the thermal gradient between body surface temperature and ambient temperature. This generator converts low temperature gradients into a DC voltage. However the resulting voltage of a few millivolts is too low to be used immediately. Thus, the DC/DC converter is utilized to transform the voltage. The applied voltage now allows a battery or a large capacitor to be charged. Considering that different body areas provide different temperature gradients between body surface and ambient conditions the neck seems to be the most profitable application [4]. Due to practicable reasons for this prototype the forearm was chosen for the TEG application.

Signal Processing (II)

Two Ag/AgCl electrodes are placed along the axis of heart on the chest wall of the subject for ECG recording. The instrumentation amplifier enables the difference amplification of both input signals. In addition, the instrumentation amplifier realizes high pass as well as low pass filter ($f_{high} = 5\,\mathrm{Hz}$, $f_{low} = 35\,\mathrm{Hz}$) to reduce influences as 50 Hz and low frequency baseline drift. The resulting modified ECG is amplified ($Gain = 20$) and subsequently fed into the microcontroller. Digitalization is performed by an integrated 24bit-$\Delta\Sigma$ ADC (sample rate = 512 Hz). Additional gain and digital filtering might be set here. The detection algorithm is meant to be based on Texas Instruments' heart rate monitor [3]. Thereby three QRS-complexes are used for the threshold comparison. The corresponding pulse periods are counted whereas their average represents current heart rate. The calculated heart rate is to be transmitted via SPI and displayed afterwards.

2.3 Limitations/Constraints

The most problematic component of the energy conversion chain is the TEG. The selection of a TEG fulfilling the necessary parameters is critical and difficult. The highest achievable temperature gradient is essential in order to reach a high output voltage. The body temperature is nearly constant and just varies in a narrow range. A far greater problem is the varying ambient temperature and a rapid warming of the TEGs by the body heat. To counteract this fact, the TEGs are equipped with heat sinks. The heat sinks are attached with adhesive thermal pads.

Considering that energy ressources are limited the most critical part at the signal processing unit is the LCD. Testing the whole system including harvester and signal processing unit the LCD might be the first part to be omitted in case of too high energy consumption.

3 RESULTS

3.1 *Harvester*

The performed functional testing of the circuits shows the successful implementation of the thermal energy harvester (Figure 2). The used circuit is based on a proposal by the manufacturer of the harvester parts [6]. A temperature gradient of about $5-8\,\mathrm{K}$ is sufficient to generate a voltage, which enables the charging process. The storage component can be loaded to a defined capacity to provide the energy for the signal processing unit and the display.

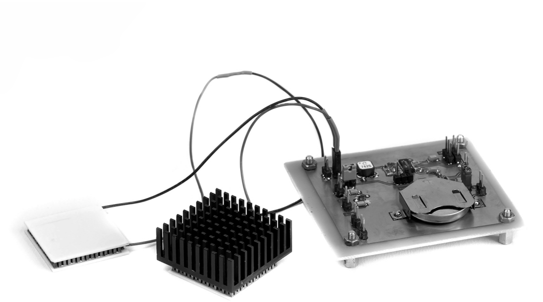

Figure 2: Thermal energy harvester with two TEGs and an additional heat sink

Voltage Conversion

The gradient between the forearm and the ambient temperature provides a short-term maximum output voltage of 140 mV up to 160 mV. A TEG output voltage of $V_{out} = 80\,\mathrm{mV}$ is sufficient to start the transformation process of the DC/DC converter. The harvester output voltage is achieved by connecting four different TEGs in series; it reaches a total of 5 V(Figure 3).

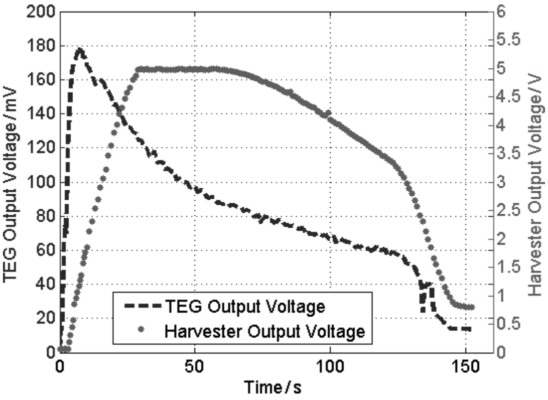

Figure 3: Diagram showing output voltage of the TEG and input voltage of the harvester, using four different TEGs in series, application site: forearm

Storage Process

The transformed voltage can be supplied either to the super-capacitor or the charging circuit to the subsequent battery. The measured output current for charging the super-capacitor is about $I_{out} = 8\,\mu\mathrm{A}$.

The capacitor charging process shows that the super-capacitor can be charged up to the applied voltage. This voltage can be held constant just for a minute (Figure 3). This underlying voltage is proportional to the temperature gradient which decreases continuously with the heat sink becoming warmer. Consequently, the resulting voltage drops steadily. Therefore, no continuous charging of the capacitor is possible.

3.2 *Signal Processing*

The built signal processing circuit (Figure 4) could not be tested in time. Two boards are created consisting of each the signal processing circuitry and a separate board for the LCD module.

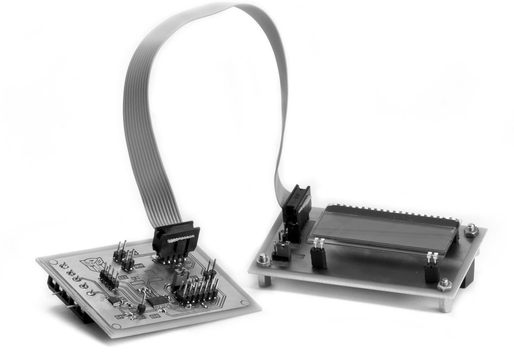

Figure 4: Layout of the signal processing and display unit

The ECG preprocessing is realized by the wired instrumentation amplifier (Figure 5).

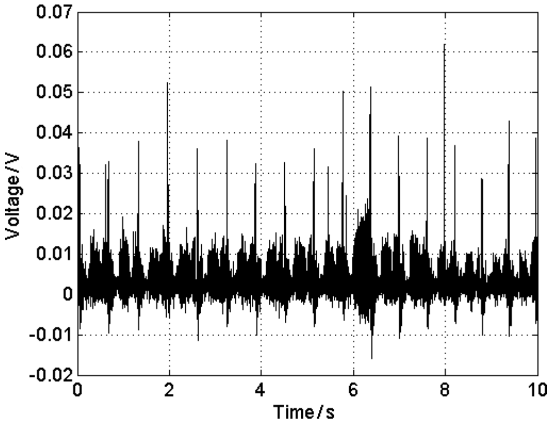

Figure 5: Excerpt of the ECG on output of instrumentation amplifier - differential amplified ($Gain = 20$)

The output of instrumentation amplifier shows ECG signal after differential amplification. R-waves can be seen as remarkable peaks in raw signal. Additional digital filtering will allow detection of the R-waves, embedded in the QRS-complexes.

4 CONCLUSION

A complete setup for a thermoelectric generator-based R-wave detection system is built. According to the presented parameters a mobile, autarkic application should be practicable.

In principle it is possible to use human body heat to operate an electronic circuit. Due to low efficiency the miniaturization of the thermal harvester is not possible. In practical experiments too many TEGs are required to realize a compact design. In addition, heat sinks are needed to prevent a rapid warming of the TEGs. There are too many constraints to develop an effective miniaturized prototype. The current prototype describes a feasibility study, which can be expanded in future investigations to increase the efficiency.

Using the thermal harvester shows the limitations of energy conversion of body heat into storable energy. A temperature gradient is essential for the harvester to generate a voltage. This gradient can be maintained only if provision is made for adequate ventilation. Moreover, the difference between body and ambient temperature has an appropriate value so that the battery charging process can be initiated.

Charging the capacitor is problematic because off the decreasing harvester output voltage. The harvester is not able to guarantee a stable output voltage of 5 V.

In respect of the battery charging process it must be noted that the theoretical load time will be very high and therefore no longer feasible.

Preprocessing and additional digital filtering will enable R-wave detection to calculate the heart rate of the subject. Forwarding the calculated heart rate to the LCD module is possible at the expense of increasing power consumption.

In future thermal generators could produce higher voltages on a smaller contact space. This increase in efficiency would allow a certain miniaturization of the harvester. The replacement of the LCD with a different kind of visualization would mean a reduction in energy consumption.

5 ACKNOWLEDGEMENT

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