ORIGINAL PAPER

SIMULATION AND MODELING OF BATTERY OPERATION USED IN REAL-TIME MONITORING EQUIPMENTS OF VITAL HUMAN PARAMETERS

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Abstract. *Today there is a significant increase in chronic diseases, of which infarct / pre-infarct is more and more present among the population and has serious consequences. For this reason, it is a permanent research theme for those involved in cardiology, especially as this type of disease is chronic and should be monitored periodically and kept under observation. Methods, systems for monitoring patients with such diseases require time and a great deal of human and financial effort. Patient monitoring systems, especially non-hospitalized, are becoming increasingly used and can provide a solution to problems that arise among the population, especially among the elderly. These systems have the advantage of real-time transmission of vital parameters and, when necessary, effective treatment and rapid medical intervention, reducing health care costs [1]. Preventing and observing these types of illness requires monitoring of vital parameters such as blood pressure (TA), heart rate (Pulse), blood oxygen concentration (SpO2), etc. The article proposes both the analysis and simulation of the functioning of a vital parameter monitoring system and the modeling of its electrical characteristics based on a complete set of measurements. The data acquisition system is designed to determine output voltage, current and power consumed with great accuracy. A Matlab application is generated to determine the approximate polynomials of the measured magnitudes and the calculated errors prove the precision of the proposed method. The time limitation of the nominal operation of this system due to the circuit's battery is also taken into account.*

Keywords: *simulation, modeling, real-time monitoring, Matlab.*

1. INTRODUCTION

Measurement of patient's vital parameters such as heart rate, oxygen and blood pressure involves the implementation of a remote hard and soft data acquisition and transmitting system. Measurement of parameters can be done in a classical way through patient collaboration with medical staff, or using portable monitoring devices capable of transmitting real-time vital data. This type of devices are generally characterized by limitations imposed by the power supply, which in the present case is represented by batteries. In this context, electronic devices for monitoring vital parameters of the patient have to meet a number of requirements, namely to have a reduced size and to consume a lower current [2-5].

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The article proposes both the analysis and simulation of the functioning of a vital parameter monitoring system and the modeling of its electrical characteristics based on a complete set of measurements. The system data acquisition is designed to determine output voltage and current and power consumed with great accuracy. A Matlab application is generated to determine the approximate polynomials of the measured parameters and the calculated errors prove the precision of the proposed method. The time limitation of the nominal operation of this system due to the circuit's battery is also taken into account [6-8].

2. DESCRIPTION OF THE PROPOSED MONITORING SYSTEM AND ITS OPERATION

The role of the battery in this case is very important. It is necessary to study the behavior of the battery in the used system. In this paper was conducted a study of the behavior of two types of batteries / accumulators in real load simulation conditions: a vital parameter measuring device.

The data measurement and transmission system was designed for a minimum current consumption in the sense of measuring the parameters for a when the system consumption is reduced then the data transmission with a GPRS / GSM device (whose consumption is higher) for a short period of time.

The battery study was carried out in the conditions of measuring / storing the parameters for a period of 60 minutes and their transmission for a period of 10 seconds. An artificial resistive load was used, with which we simulated the consumption of the monitoring system parameters in the two situations: measurement and transmission.

For the analysis was used a Li-Po battery with a voltage of 4.2V (peak charging state) with a current of 2000mAh, respectively a NiMH battery made of 4 cells of 1.2V and a current of 2000mAh. The battery voltage of NiMH batteries is 4.8V. To perform an analysis with the same value of battery voltage, in the case of the NiMH battery we have made a voltage divider whose electric circuit is represented in Fig. 1.

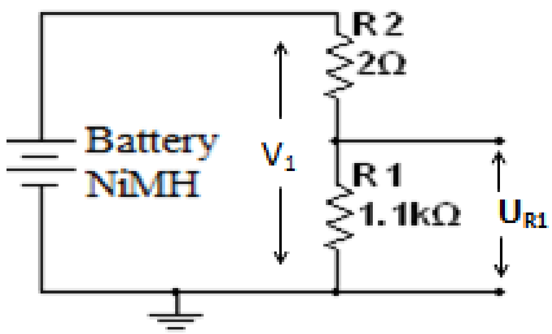

Figure 1. Voltage divider electrical scheme.

Voltage divider formula is presented below:

$$U_{R1} = (V_1 * R_1)/\,(R_1 + R_2) \quad (1)$$

The battery analysis hardware system contains the following elements: the current transducer, the device for reading and storing the values of battery voltage and current consumed by the load, and the maximum load connection device. The block diagram of the analyzed system is shown in Fig. 2.

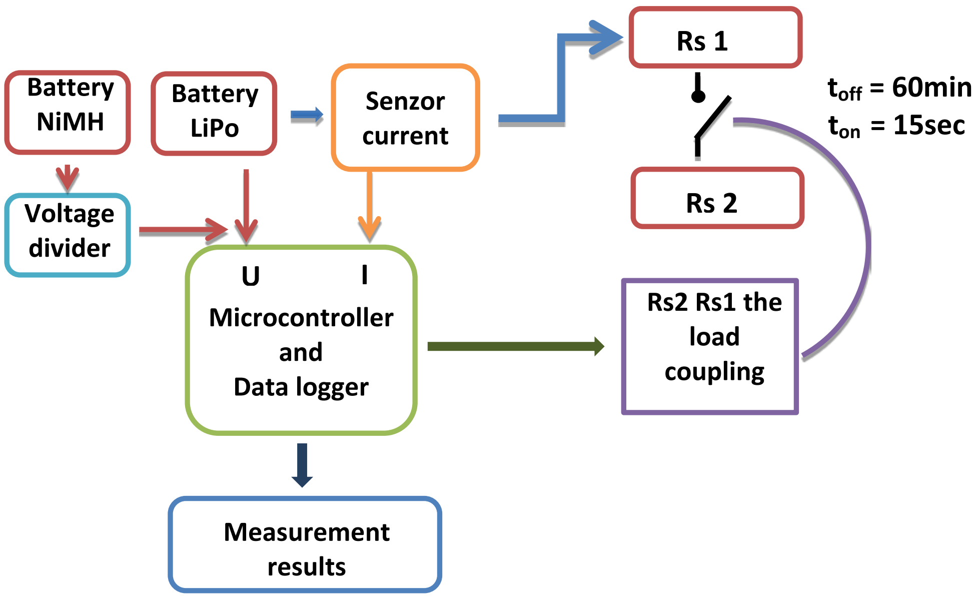

Figure 2. The block diagram of the system.

The hardware system consists of a current sensor, an Arduino board with Atmega controller, a shield data logger, an additional load-carrying device, a resistive load or a voltage divider. Current absorbed by the load is read using a current sensor. The load absorbs an initial current corresponding to the vital parameter measurement for 60 minutes (about 150mAh) after which a relay circuit controlled by the device's microcontroller connects to the initial Rs1 load, the Rs2 load simulating the current consumption (350 mA) corresponding to the situation when the GPRS / GSM device is transmitting for 15 seconds. The current sensor is made of a shunt and an amplifier circuit (Fig. 3).

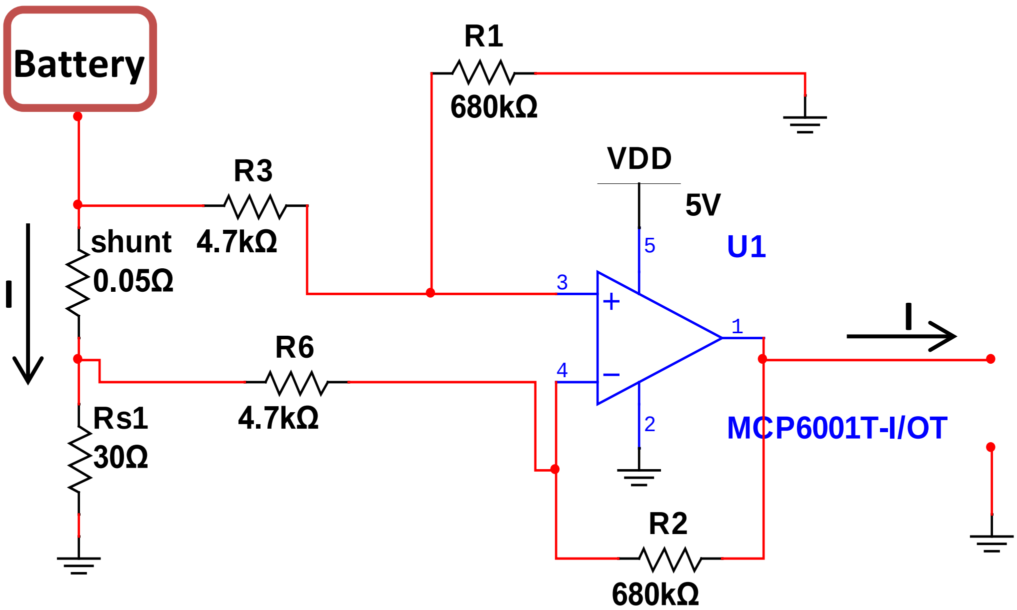

Figure 3. Current sensor scheme.

Shunt is a precision resistor with a resistance value of 0.05Ohm. The value of the voltage read on the resistor due to the current passing through is very small and for that was made an amplifier with a gate of an operational amplifier (AO) to get a measurable signal. The gain of the amplifier is:

$$G = R_2 / R_6 = 144.68 \quad (2)$$

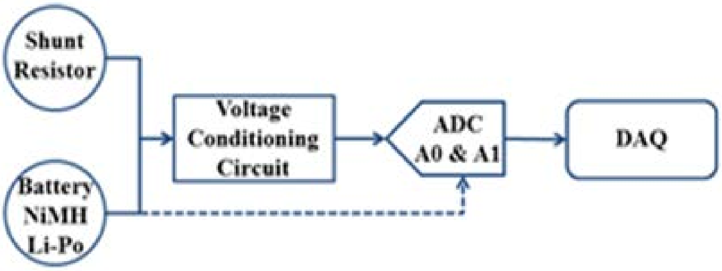

Figure 4. Block diagram of the acquisition, processing and storage of battery system data.

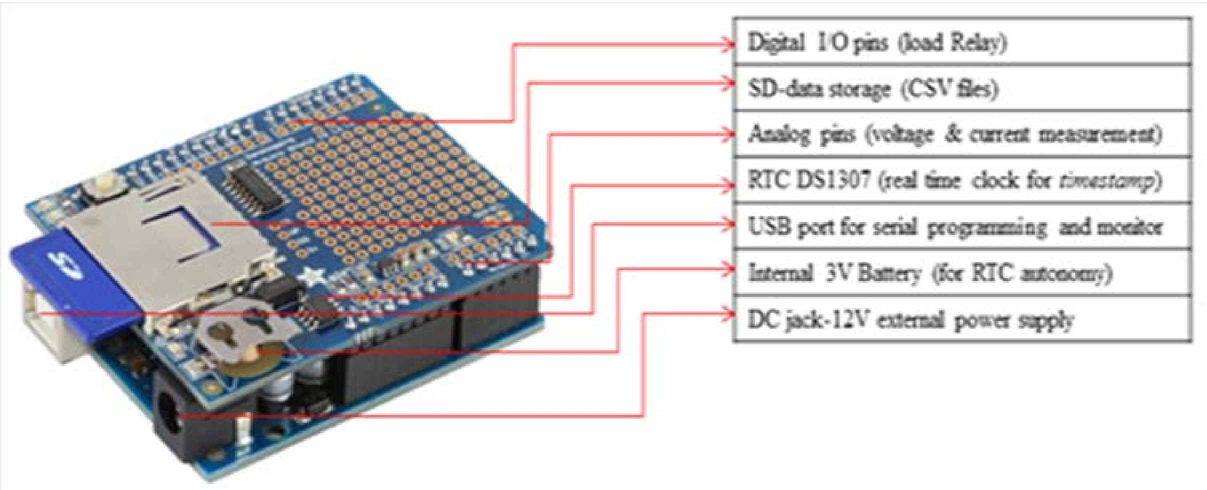

Figure 5. Arduino-Shield data logger.

The block diagram of the acquisition, processing and storage of battery system data is shown in Fig. 4. Fig. 5 shows the Arduino-Shield data logger device that monitors battery voltage and current absorbed by the load. The data is stored on a SD card. The acquired data is processed using the Mathlab program.

3. THE DATA ACQUISITION ALGORITHM AND THE MODELING OF THE ELECTRICAL CHARACTERISTICS OF THE SYSTEM

3.1. THE DATA ACQUISITION, PROCESSING AND STORAGE ALGORITHM

The data acquisition, processing and storage algorithm is presented in Fig. 6.

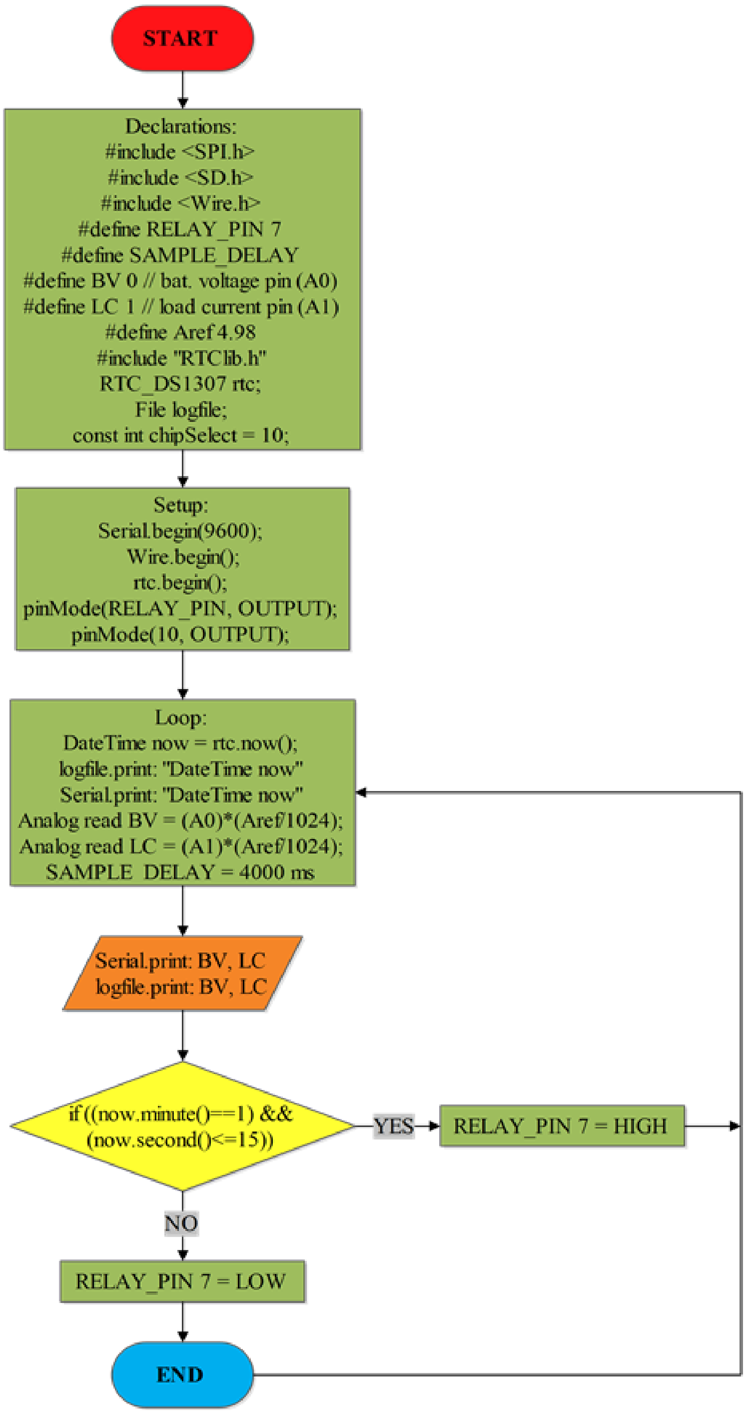

Figure 6. Flowchart of data acquisition algorithm.

The algorithm developed by us contains multiple logic blocks that reads the analog data, converts it into digital values with the 10 bit ADC and stores it on a CSV table file or displays it on the serial port of the Arduino board. The stored data is represented by the algorithm functions: BV (battery voltage), LC (load current) and DateTime (timestamp). The BV function is mapped on the A0 analog pin of the Arduino and it reads the battery voltage of either Li-Po or Ni-Mh.

The LC function is mapped on the A1 analog pin of the Arduino and it reads the load current in the circuit. There are two loads read by this pin: the continuous reading load and the triggered load which we will describe next. The DateTime function reads the RTC (real-time-clock) of the shield and generates a timestamp for each reading of the Arduino into the CSV table file.

The readings are executed and stored at every 5 seconds, but after each 60 minutes, the algorithm triggers for 15 seconds, the RELAY_PIN function mapped on the D7 digital pin of the Arduino. The relay switches the circuit on a larger load to simulate the data transmission current load of the GPRS module.

3.2 MODELING THE U(t), I(t), AND P(t) CHARACTERISTICS OF THE BATTERIES

For this study were used two types of batteries: Li-Po and Ni-Mh, and the battery discharge was monitored, during that time acquiring 23512 samples. During this period the batteries were fully discharged. The data obtained from the monitoring led to the following results:

1) LiPo battery

Fig. 7 shows the variation of the time-dependent current, I = f (t), and in Fig. 8 the function I = f (t) is represented as a result of the approximation using a Matlab interpolation function [9-13] to eliminate the peaks considered insignificant in the ratio with the total number of samples of the monitoring. Of the total number of samples taken, only 0.38% represents the peak values of the current occurring at the maximum system consumption.

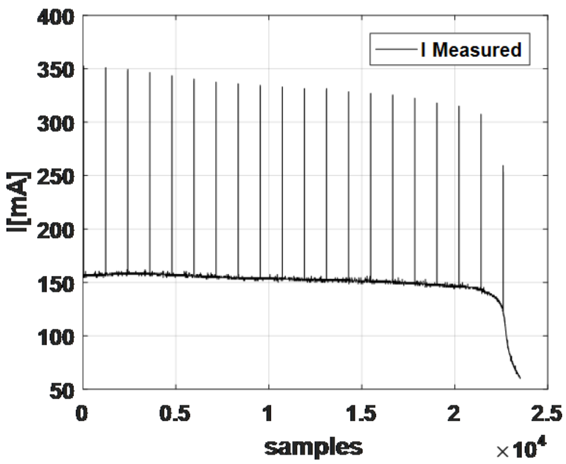

Figure 7. I=f(t) characteristic.

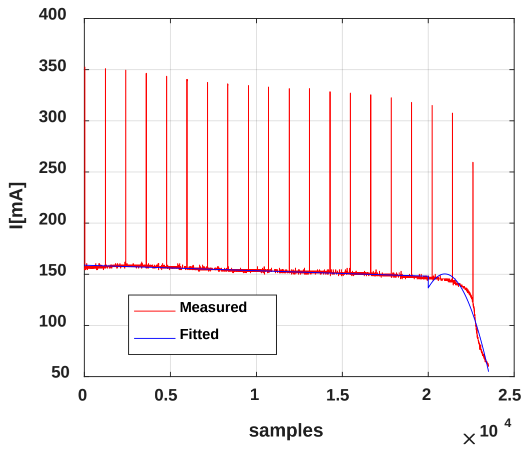

Figure 8. I=f(t) fitted characteristic.

Interpolation led to a polynomial function of the next form:

$$I(s) = \begin{cases} -538.1591E-6 \cdot s + 158.8944E0, \text{ if s} \leq 20000 \\ -14.7187E-6 \cdot t^2 + 617.1339E-3 \cdot s - 6.3185E3, \text{if } 20000 < s < 23512 \end{cases} \quad (3)$$

and the R_{MSE} is :

$$R_{MSE} = 0.972$$

The variation of the battery voltage U = f (t) is represented in Fig. 9, and the approximate characteristic U = f (t) obtained by interpolation is shown in Fig. 10.

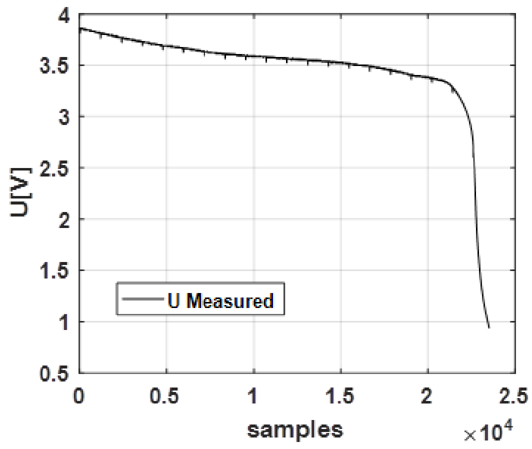

Figure 9. U=f(t) characteristic.

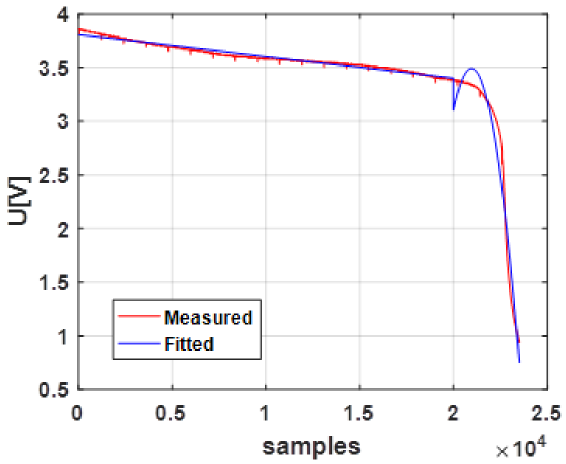

Figure 10. U=f(t) fitted characteristic.

Interpolation led to a polynomial function of the next form:

$$U(s) = \begin{cases} -20.3529E-6\cdot s + 3.8062E0, \text{if } s \le 20000 \\ -421.3251E-9\cdot t^2 + 17.6637E-3\cdot s - 181.6444E0, \text{if } 20000 < s < 23512 \end{cases} \quad (4)$$

and the R_{MSE} is :

$$R_{MSE} = 0.975$$

Both in the case of the current and voltage variation characteristic after a period of 20000 samples, there is a sudden drop of values. The sampling period of 20000 samples corresponds to a 28-hour time interval, after which the battery undergoes a full discharge, which is an important information for analyzing the system's nominal operation.

Considering that for the operation of the battery-powered system under optimum operating conditions it is necessary for the battery to provide a supply voltage for as long as possible, which must not exceed 10% of the initial voltage of the charged battery . Under a battery state of charge value of 10% the system can no longer operate under optimal conditions. Taking this into account, we find that the LiPo battery can provide 10 hours of system autonomy. The power P developed by the battery is determined by:

$$P = U \times I \text{ (W)} \quad (5)$$

Power (P) is shown in Fig. 11.

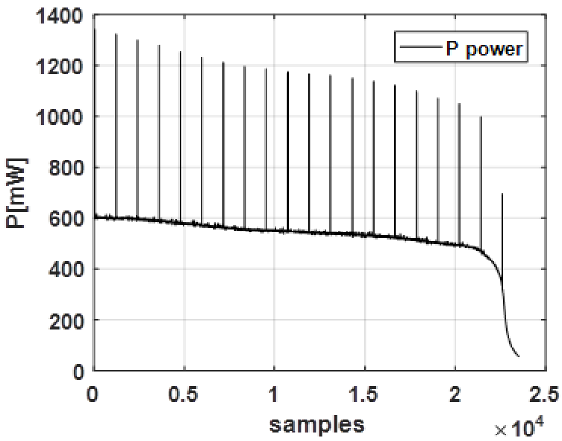

Figure 11. Battery power output characteristic.

2) NiMH battery

The NiMH battery was tested under the same conditions as LiPo. The graph of the variation of the current is represented in Figs. 12 and 13 is represented the characteristic of the approximation by interpolation.

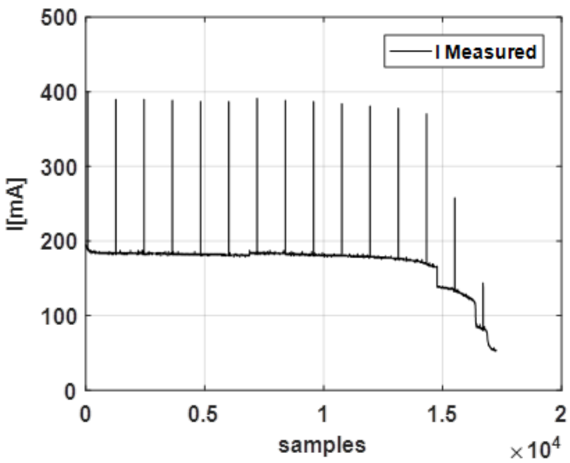

Figure 12. I=f(t) characteristic of NiMH battery

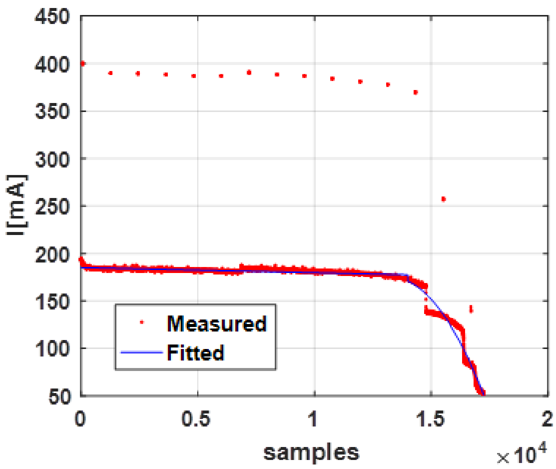

Figure 13. Fitted I=f(t) characteristic.

Interpolation led to a polynomial function of the next form:

$$I(s) = \begin{cases} -531.2711E-6 \cdot s + 185.1882E0, \text{if } s \leq 14000 \\ -7.9355E-6 \cdot t^2 + 211.1607E-3 \cdot s - 1.2301E3, \text{if } 14000 < s < 17250 \end{cases} \quad (6)$$

and the R_{MSE} is :

$$R_{MSE} = 0.960$$

The variation of the battery voltage U = f (t) is represented in Fig. 14, and the approximate characteristic U = f (t) obtained by interpolation is shown in Fig. 15.

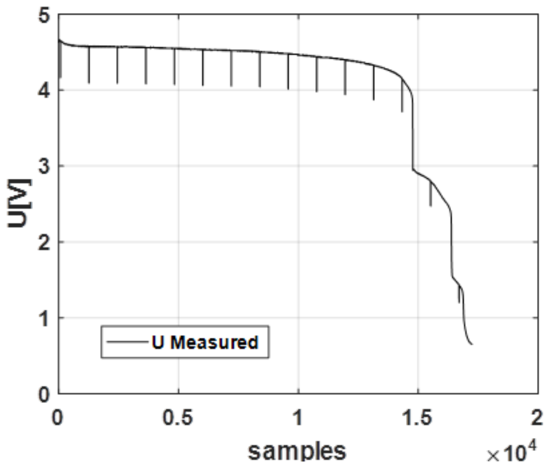

Figure 14. U = f(t) characteristic.

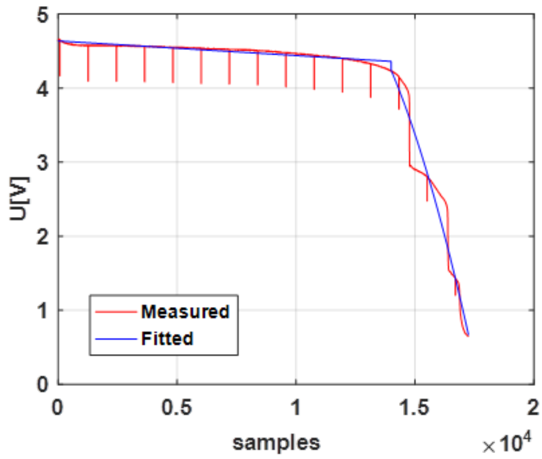

Figure 15. Fitted U=f(t) characteristic.

Interpolation led to a polynomial function of the next form:

$$U(s) = \begin{cases} -19.6957E-6 \cdot s + 4.6350E0, \text{if } s \leq 14000 \\ -104.7051E-9 \cdot t^2 + 2.1740E-3 \cdot s - 5.6738E0, \text{if } 17250 < s < 17250 \end{cases} \quad (7)$$

and the R_{MSE} is :

$$R_{MSE} = 0.980$$

The sampling period of the NiMH battery is noticeably lower, the battery reaching the discharge stage much faster. In this case it is observed after a period of 14000 samples that there is a sudden drop in their values. The sampling period of 14000 samples corresponds to a time interval of 19 hours, after which the battery undergoes a complete discharge. Taking into account the range of battery voltage variation, it will provide the required voltage for optimal system operation for a short period of time. The power (P) generated by the battery is calculated with relation (5) and is illustrated in Fig. 16.

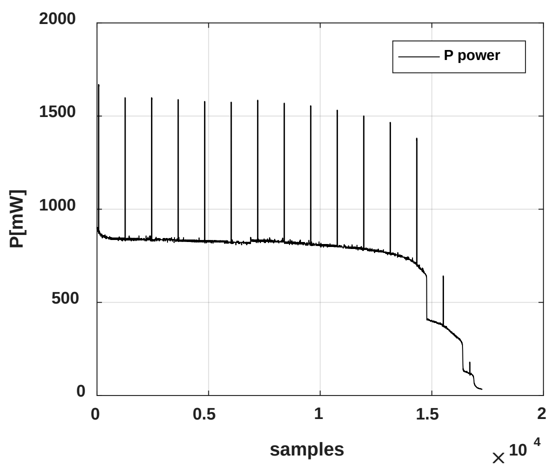

Figure 16. Power output characteristic of the NiMH battery.

4. CONCLUSIONS

The present article is done with a system proposed by the authors [14]. The data acquisition system is designed to determine output voltage, current and power consumed with great accuracy.

The acquired data is processed with a Matlab application created by the authors to determine the interpolation polynomials of the measured data and the calculated errors prove the precision of the proposed method. The time limitation of the nominal operation of this system due to the circuit's battery is also taken into account. Taking into account the graphical representations of the evolution of the battery discharge over time and due to the properties of the two types of technologies used in the construction of the batteries, the LiPo type battery ensures the functioning of the monitoring system for a longer period of time then the NiMH battery, in optimal consumption conditions.

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