World Academy of Science, Engineering and Technology
International Journal of Materials and Textile Engineering
Vol:2, No:8, 2008

Decreasing Power Consumption of a Medical E-textile

E. Shahhaidar

Abstract**—**In this paper we present a novel design of a wearable electronic textile. After defining a special application, we used the specifications of some low power, tiny elements including sensors, microcontrollers, transceivers, and a fault tolerant special topology to have the most reliability as well as low power consumption and longer lifetime. We have considered two different conditions as normal and bodily critical conditions and set priorities for using different sensors in various conditions to have a longer effective lifetime.

Keywords**—**ECG, E-Textile, Fault Tolerance, Power consumption.

I. Introduction

ELECTRONIC textiles (E-textiles, sometimes also called smart fabrics) not only can be worn, but also can monitor, do local computing, and communicate wirelessly [1]. Sensors and simple computing elements are embedded in electronic textiles or inside strings. The target is to gather important information, monitor vital signs, and send them for further processing (possibly through a wireless channel).

The use of fabrics as a platform for electronic components has made more applications feasible in wearable computers. Applications like medical monitoring (infants or patients), individual information processing systems, or remote monitoring of the military personnel or aerospace applications and many more [2].

Having passed just less than two decades of such pervasive computing systems, many applications in all fields are defined and in many cases have been approached to implement.

But there are some tribulations to reach this technology. Power consumption, fault models, redundancies, and performance are just some of the problems to be investigated. Solution of these problems can be examined by hardware modeling or software simulating.

Generally, these textiles are not connected to a constant power supply. Thus, they have power consumption limitations.

The other problem is the existence of faults in textile. Since fabric is a necessary environment for an electronic textile which can have physical defects originated from the process or the situations that the fabrics were opposed to. These defects can lead to short circuit or open circuit on textile which finally made the results of the computing components wrong [3]. So considering the fault tolerance problem during the design stage is very important.

E. Shahhaidar is with Khajeh Nasir Toosi University of Technology, Tehran, Iran (phone: +98-912-3387530, email: shahhaidar@eetd.kntu.ac.ir).

In this study, to increase the lifetime of the total system, we chose low power electronic components. Besides; a technique has been used to give priority to different components to reduce power consumption further.

On the other hand, the locations of components are such that the elements are objected to the least faults originated from tears. Moreover, the architecture and the redundancy of the computing element would increase fault tolerance.

We used simulation for two main reasons, first of all because implementing real models to find the performance of the textiles in case of fault occurrence is difficult. Besides; electronic textile technology is in its early stages [3].

Firstly; this paper proposes a general-medical application for the electronic garment, then considering the maximum fault tolerance topology, the locations and the numbers of sensors, microcontrollers, transceivers and the way of routing will be identified.

II. A Reliable Electronic Textile

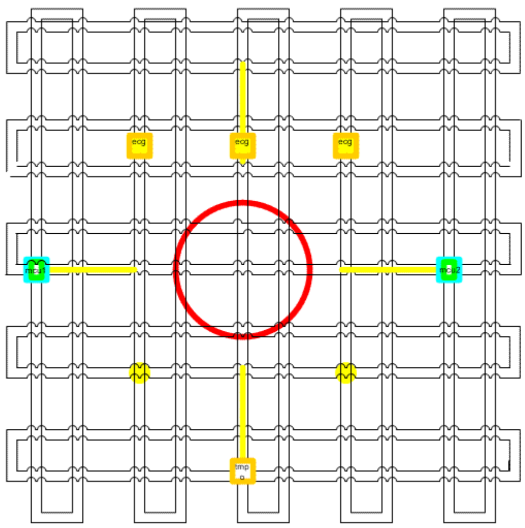

Fig. 1 The first design of the e-garment considering torus architecture and the maximum reliability

The initial design of the garment had a torus or token grid [4] architecture considering XY scheme of the textile and maximum reliability (Fig. 1). In this design some sensors including ECG leads and the ambient temperature sensor are considered single (without redundant) but the locations of them are such that they are subjected to the least possible fault and tears (Fig. 2) [5]. It can be inferred from Fig. 2 that if the textile has 20 warps and 20 wefts with mesh architecture, corners and the middle of the textile (The circle in the middle of Fig. 1) have maximum failure edge probability (about 0.05). So those single sensors can be located in the safest places. Furthermore, each link can be considered as two parallel wires instead of one [5] with a definite distance to have more fault tolerance.

The last note to be considered when locating the elements is that the load should be evenly distributed across the garment.

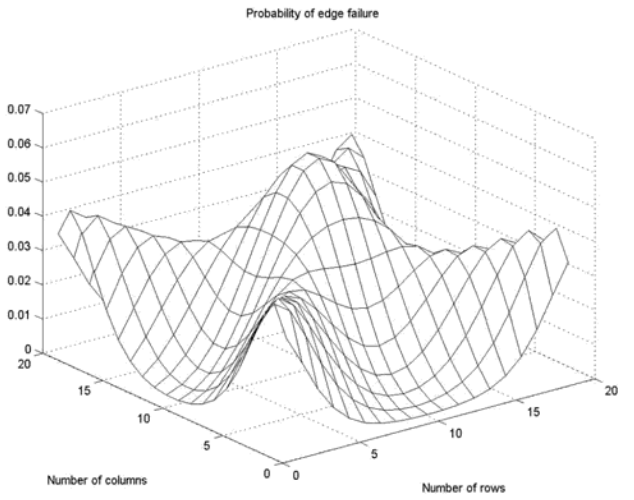

Fig. 2 Probability of edge failure in the grid for all possible tears

A. *Selection of Elements*

We decided to use the specification of some real components to estimate almost the real power consumption. The final goal is to optimize the power consumption of the system. But first and foremost problem is to define the application of the electronic textile.

As mentioned before, we considered a general-medical application for our study. So, we needed one or more general application sensors, medical application sensors, analog to digital converters, microcontrollers, transceivers, batteries, and some other essential components. Whereas the garment was considered for a person (it was a wearable electronic textile), all components should be tiny enough to be unobtrusive and have the least possible power consumption to help increasing lifetime of the system.

There were many general application sensors used in such systems yet e.g. accelerometer, magnetometer, light, and temperature sensors [5], [6], [7], pressure, and flex sensors [5], [8], Microphones [3], [4] for various applications like motion capturing, beamforming, etc. What we selected for our purpose were the specifications of a light sensor [9], an accelerometer and two temperature sensors.

Also, since one of the most important applications in wearable computers and smart textiles is telemedicine, many different kinds of medical sensors suitable to implant in electronic textiles have been made and used by scientists. Sensors like ECG, respiration electrodes, pulse oximeter, blood pressure, galvanic skin response sensors [5], [10], [11] are just some examples of biomedical ones. But the specification of some of them (e.g. what are used in [10], and [11]) were not available since they were made in special laboratories or research groups. Hence, among all possible medical sensors, the specifications of the ECG sensor called QUASAR made by University of California Irvine were used for this design. This sensor works with merely three leads, and does not need any jells, sticks or skin preparations. Every lead has a power consumption of about 1 mW which can be supplied with a lithium coin cell battery [12].

The accelerometer chip was H34C from Hitachi semiconductor with a 3-axis accelerometer and an internal temperature sensor [13]. The accelerometer can regulate the results according to the temperature changes to have the most accuracy. Besides; the internal temperature sensor can be used for measuring body temperature. Another temperature sensor (MAX6605) [14] was selected to measure the environment temperature. Having done a comparison between the results of these two temperature sensors, the wearer's body temperature changes can be realized.

The information gathered by sensors should be sent to an ADC, then to a microcontroller and finally sent to a PDA by a transceiver. The last stage is the transmission of the information from PDA to the center (which can be a hospital or a central military service) probably through a wireless channel. The ultimate processes and conclusions will be done there.

To ensure that the information will not be lost under no circumstances (reliability with order of almost 10-5), two processors are considered: one of them as the main processor, the other one as the redundant.

The main processor samples from different sensors. Whenever this processor fails for any reason, an interrupt alerts the redundant processor to be activated and continue the operation as the main processor. By polling from the first (main) processor, the interrupt will be realized.

Processors which had been used for different electronic textile and wearable computer applications were ADSP2188 [3], [4], Atmega128 AVR [5], MSP430 [15] , and the microcontroller part of nRF24E1 [16] so far. Besides; there were various RF transceivers for the transmission unit. For instance, ZL70101 from Zarlink Semiconductor [17] and nRF2401 (transceiver part of nRF24E1) [18] seemed suitable choices. ZL70101 is a medical implantable transceiver produced in 2007 and has less power consumption than nRF2401. But nRF24E1 has some other significant features like the ability to monitor the battery voltage and having a transceiver, a simple microcontroller with 8051 compatible CPU core and an AD converter are all in a single chip which can be so useful for such kind of applications. This chip can be supplied by a single power supply in 1.9~3.6 volts and since its production date (2004), it has the most usage in wireless applications. During recent years some electronic, wearable textiles with various applications [19], [20] has been made by the usage of this chip.

Hence for the total part of the transceiver, ADC, and the microcontroller nRF24E1 is considered.

Other components are two octal ADG714 switches [21] (the control word of which will be provided by the microcontroller to activate/inactivate sensors), two Lithium Polymer batteries, two step down DC/DC converter, two battery protection IC, three coin cell battery for ECG leads.

B. *Final Configuration*

Having selected the routing method like what is in [22], the ultimate configuration of the system will be like Fig. 3. Each square located in left and right includes an nRF24E1, a light sensor, an accelerometer, a skin temperature sensor, a DC/DC converter, a Li-Po battery and its protection IC, and an octal switch; three squares at the top the figure will be 3 ECG leads; and the square at the bottom of the page is the location of the ambient temperature sensor. And the lines represent the wires embedded in strings of the textile.

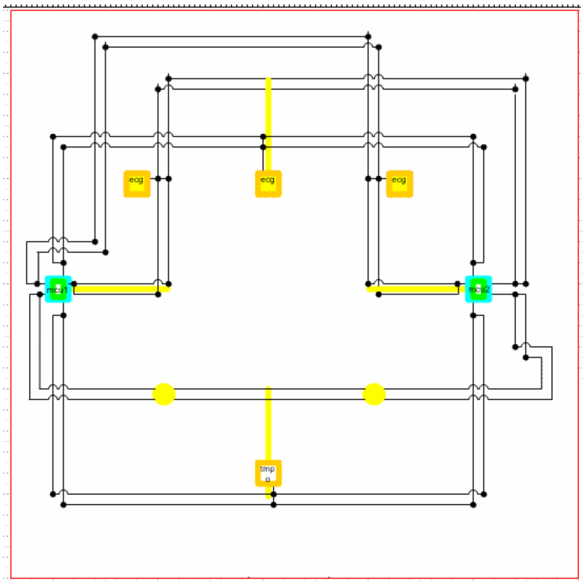

Fig. 3 The ultimate configuration of the system

III. Simulation of the System

In [3] a simulating tool, called power tracker, has been made to monitor the operation of sensing elements. This simulation software is just for estimating the power consumption of each computing components on electronic textiles. In fact, power tracker in [3] is a beginning of a complicated timing algorithm and power routing which can be used in future.

But production of a simulation environment which comprises all aspects of an application in an electronic textile is intricate. Consequently, it is better to use present softwares [4]. Ptolemy [23] sounds a appropriate simulation environment for simulating the whole performance of the system including sensor behavior and the process of nodes to cover all important aspect of the system. [4]

In [3], [4], [24], and [25] simulation of electronic textiles have been done based on a combination of softwares like Ptolemy II, Matlab or some programming languages like C++ and Java. By Ptolemy different aspects of designing an electronic textile designs, including physical environment which they should be used in, sensors behavior inside the fabric, the network on the textile, system power consumption, application execution and the system software, can be modeled. [4]

This software can define various domains in one or more domains in a hierarchy form and this is the main reason to select this software for simulating electronic textiles environment.

From the highest level of the system to the lowest one (inside chips and modules) can be modeled in a way like what is shown in Fig. 4 through Fig. 6.

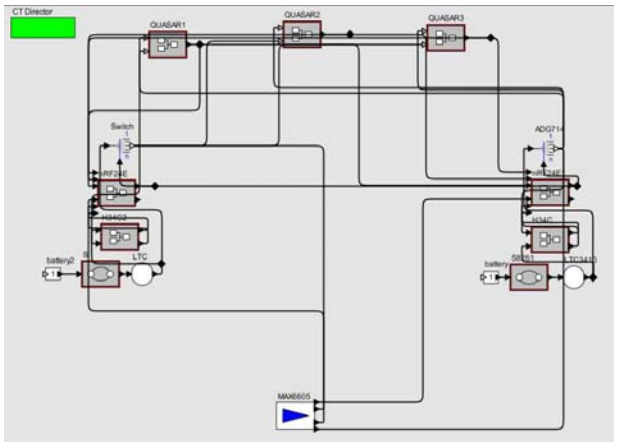

Fig. 4 Simulation of the system (at the highest level) by Ptolemy II

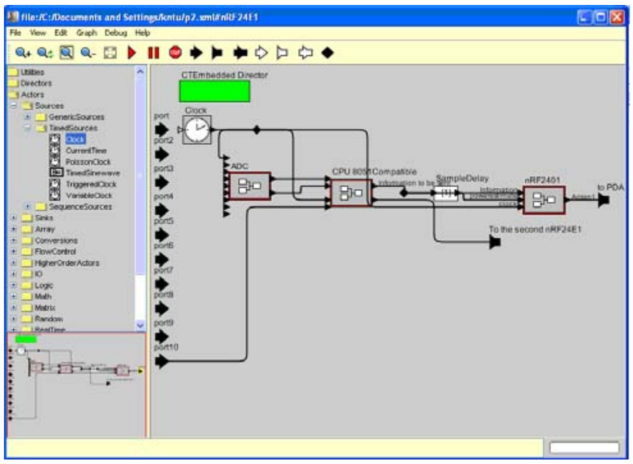

Fig. 5 Inside the nRF24E1

At the end, a Visual C++ program was written to track the power consumption of each element, and then estimate the total power consumption and the lifetime of the system. This program can get the input information including the number of transmissions and receptions of the information in a day, the number of active sensors, batteries, and microcontrollers manually to find out the lifetime of the system. To increase the lifetime of the system, we considered a novel strategy in this design.

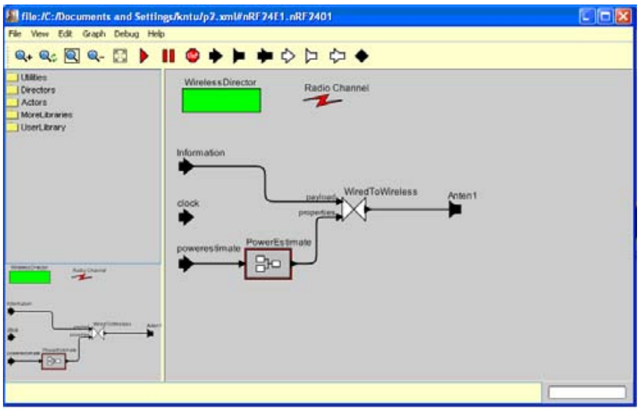

Fig. 6 Inside the transceiver module of the nRF24E1

The strategy is giving priority to activation of the sensors in different conditions, i.e. sensors which are really urgent for an application in a special circumstance should be activate at that moment and the sensor which is not vital then can be inactivated.

A. Normal Conditions

Regarding what was said before, assuming that the system is in normal condition (all batteries are charged and the wearer does not need to get his electrocardiogram), one nRF24E1, body temperature sensor, the accelerometer and the environment temperature sensor, DC/DC converter and the Li-Po battery are active. In this situation, mainly the transmission and reception of the information affects the power consumption.

Assuming that transmitting of the information (through the transceiver module of the nRF24E1 to the PDA wirelessly) every five minutes and receiving the information from the center twice every day, the system lifetime can be about 16 days.

Another processing and wireless node includes nRF24E1, a light sensor, a H34C, a Li-Po battery, a DC/DC converter and a switch were added to the scheme as redundancy, to raise the fault tolerance of the system. The second nRF24E1 can poll the first nRF24E1 once in a while to be assured that it is working. Once the first microcontroller was disabled for any reason (including battery full discharge), the redundant elements are activated to follow the main nRF issues. Depending on the period of the polling, this technique increases the lifetime too. For instance, if the redundant nRF checks the main nRF every five minutes, the system can last more than 20 days (Fig.7.).

The network architecture is such that all of the information gathered by sensors is sent to both microcontrollers simultaneously.

B. Critical Conditions

As mentioned before, different kinds of conditions can be defined and considered in an application, one of which is while the person is bodily in trouble and electrocardiogram information of the wearer is needed. In such a situation, the environment temperature sensor, body temperature sensor, light sensor and the accelerometer will be inactivated and assuming that the ECG sensors supplied by their own coin cell batteries the system will last about 7 days.

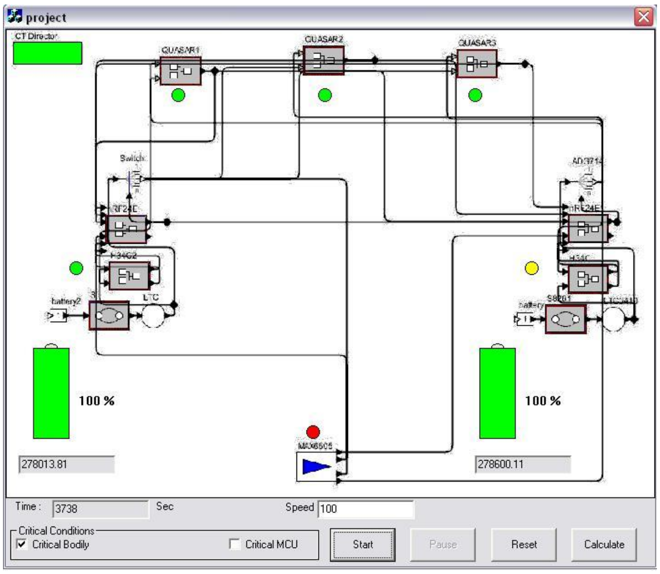

Fig. 7 The system simulation dialog box to estimate the lifetime

IV. Conclusion

In this paper a novel design of a wearable electronic textile with the aim of increasing fault tolerance as well as decreasing total power consumption was modeled and simulated by Ptolemy II softwares, after selecting some real components, using specifications of them, and doing some calculations we estimated the lifetime in two different conditions by a program written by Visual C++.

Appendix

A. Explanations about nRF24E1

The nRF24E1 microcontroller is instruction set compatible with the industry standard 8051. Instruction timing is slightly different from the industry standard, typically each instruction will use from 4 to 20 clock cycles, compared with 12 to 48 for the “standard”. This translates to a 3X improvement in execution time for most instructions.

The interrupt controller is extended to support 5 additional interrupt sources; ADC, SPI, RF receiver 1, RF receiver 2 and wakeup timer. There are also 3 timers which are 8052 compatible. An 8051 compatible UART that can use timer1 or timer2 for baud rate generation in the traditional asynchronous modes is included.

The nRF24E1 can be set into a low power down mode under program control, and also the ADC and RF subsystems can be turned on or off under program control. The CPU will stop, but all RAM’s and registers maintain their values. The low power RC oscillator is running, and so are the watchdog and the RTC wakeup timer (if enabled by software). The current consumption in this mode is typically 2μA.

The device can exit the power down mode by an external pin (INT0_N or INT1_N) if enabled, by the wakeup timer if enabled or by a watchdog reset.

It is more convenient to use the built-in SPI interface to do the most common transceiver operations as RF configuration and shock Burst™ RX or TX.

The Shock Burst™ technology uses on-chip FIFO to clock in data at a low data rate and transmit at a very high rate thus enabling extremely power reduction.

When operating the nRF2401 subsystem in Shock Burst™, you gain access to the high data rates (1 Mbps) offered by the 2.4 GHz band without the need of a costly, high speed microcontroller (MCU) for data processing. By putting all high speed signal processing related to RF protocol on-chip, the nRF24E1 offers the following benefits:

• Highly reduced current consumption

• Lower system cost (facilitates use of less expensive microcontroller)

• Greatly reduced risk of 'on-air' collisions due to short transmission time.

The AD converter is normally clocked by the CPU clock divided by 32 (125 to 625 kHz), and the ADC will produce 2 bits of result per clock cycle. The converter is by default configured as 10 bits. For special requirements, the AD converter can be configured by software to perform 6, 8 or 12 bit conversions, the only parameter changes is the conversion rate [18].

REFERENCES

[1] D. Marculescu, R. Marculescu, N. Zamora, M. Jones, P. Kholsa, S. Park, S. Jayaraman, S. Jung, C. Lauterbach, W. Weber, T. Kirstein, D. Cottot, J. Grzyb, G. Tröster, T. Martin and Z. Nakad, "Electronic textiles: A Platform for Pervasive Computing," in Proc. IEEE; VOL.91; NO.12, pp.1993-2018, Dec. 2003.

[2] D. Marcuescu, R. Marcuescu, and P. Kholsa;" Challenges and Opportunities in Electronic Textiles Modeling and Optimization";DAC June 2002, New Orleans, L.A, USA, 2002.

[3] T. Sheikh," Modeling of Power Consumption and Fault Tolerance for Electronic Textile", MSC thesis for electrical engineering submitted to the faculty of Electrical and Computer engineering, Blacksburg, VA, 2003.

[4] Z. S. Nakad," Architectures for E-textiles"; PhD thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in Computer engineering, Dec.2003.

[5] R. Jafari," Medical Embedded Systems"; PhD thesis submitted to the faculty of the University of California Los Angeles in Computer Science; 2006.

[6] A. Golding and N. Lesh," Indoor Navigation Using a Diverse Set of Cheap Wearable Sensors"; in ISWC, pp. 29-36, 1999.

[7] K. V. Laerhoven and O. Cakmakci, \What shall we teach our pants?" in Proceedings of the Fourth International Symposium on Wearable Computing. ISWC 2000, pp. 77-83, October 2000.

[8] J. Edmison, M. Jones, Z. Nakad, and T. Martin;" Using piezoelectric materials for wearable electronic textiles", Proceedings of Sixth International Symposium on Wearable Computers, (ISWC 2002), pp. 41-48, 2002.

[9] www.hamamatsu.com

[10] F.carpi, D.De Rossi; "Electroactive Polymer-Based Devices for e-Textiles in Biomedecine"; IEEE Transactions on Information Technology in Biomedecine, VOL.9, No.4, pp.297-318, Dec.2005.

[11] www.lifeshirt.com

[12] www.QUASARUSA.com

[13] www.hitachimetals.com

[14] www.maxim-ic.com

[15] P.L. Lo B., S. Thiemjarus, R. King and G. Z. Yang; "Body Sensor Network – A Wireless Sensor Platform for Pervasive Healthcare Monitoring"; Department of Computing, Imperial College London, South Kensington Campus 180 Queen's Gate, London, SW7 2AZ, United Kingdom.

[16] C. Park, P.H. Chou; "Eco: Ultra-wearable and Expandable Wireless Sensor Platform"; in Third International Workshop on Body Sensor Networks (BSN2006), April 2006.

[17] www.zarlink.com

[18] www.nvlsi.no

[19] C.Park, P.H.Chou, Y. Bai, R. Matthews, and A. Hibbs; "An Ultra-Wearable, Wireless, Low Power ECG Monitoring System"; Quantum Applied Science & Research (QUASAR), Inc & University of California, Irvine, CA. USA, 2006.

[20] C. Lombriser, N. B. Bharatula, D. Roggen, G. Tröster," On-Body Activity Recognition in a Dynamic Sensor Network"; Wearable Computing Lab ETH Zürich, Zürich, Switzerland,2007.

[21] www.analog.com

[22] I. Locher, T. Kirstein, and G. Troster; "Routing Methods Adapted to E-Textiles"; Wearable Computing Laboratory; ETH Zurich; Switzerland; 2004.

[23] Ptolemy Project, Ptolemy II Heterogeneous Concurrent Modeling and Design in Java,UC Berkeley. http://ptolemy.eece.berkeley.edu.

[24] T. Martin, M. Jones, J. Edmison, T. Sheikh, and Z. Nakad, "Modeling and Simulating Electronic Textile Applications", LTES' 04, ACM, Washington, DC, USA, June11-13, 2004.

[25] C.M. Zeh; "Softwear: A Flexible Design Framework for Electronic Textile Systems"; Master's thesis in Computer Engineering; Virginia Polytechnic Institue and State University, April 2006.