m-GreenCARDIO Embedded System Designed for Out-of-Hospital Cardiac Patients

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***Abstract*—Today's electronic systems have evolved greatly and enable the design of systems that are safer, more competitive and also more flexible in terms of their built-in features and power consumption. As we see, the number of applications in the medical field and in adjacent areas have skyrocketed, so that monitoring terminals or mobile analysis systems can be purchased relatively easily. This paper presents and describes the concept, results and theory of operating the m-GreenCARDIO device, designed for remote monitoring of out-of-hospital patient's heart condition. This implementation helps to make medical instrumentation more efficient, making it accessible to a larger social range, by the means of Internet of Things (IoT). Thus, through this project, a real and flexible collection of ECG data from patients can be acquired, obtaining valuable information that can be used for remote research and diagnosis.**

Keywords—Electrocardiography, Internet of Things, Embedded software, Telemedicine, Microcontrollers.

I. INTRODUCTION

With the development of the IoT concept, of the GSM/GPRS infrastructure and of wireless communications (M2M), the patient was no longer depending on the landline. Today's electronic embedded systems are advanced in many ways such as, processing power, low power consumption, implementation of multiple communications interfaces or the easy integration of the IoT concept [1], [2]. Therefore, the current evolution of the embedded systems is by far an important step in the field [3]. The first mobile telemedicine systems allow the transmission from ambulances of the patient's parameters for remote assistance and preparation of emergency services.

The IEC60601 is a series of technical standards for the safety and performances of medical electrical equipment, published by the International Electrotechnical Commission. As a requirement for most markets, IEC60601 represents a solid support for many companies in order to provide medical devices that are effective and safe.

With the vital need to save energy, the solution chosen for the implementation of this project must be reliable and scalable, to achieve rapid assessments and to significantly reduce time to market launch. For example, through the *hSensor* platform, a wearable electrocardiogram (ECG) module can be designed with an energy efficiency of more than 50% compared to the existing solutions.

In decade nine, Siemens attempted an alliance with Philips in order to develop a digital solution for cardiac monitoring, using phone landlines. This alliance resulted in a new product that has never been developed beyond the micro-production stage. The causes of failure were many, among which we can mention the conditioning by the telephone connection and the skyrocketing costs related to the overall implementation of the system. Thus, these causes have greatly reduced the applicability of the solution, the system being abandoned in 1993. The information technology currently provides the infrastructure for remote cardiac healthcare, known as telemedicine. At this point, the tele-cardiology is an ascending trend, competing with tele-radiology as the main applications of telemedicine. Currently, the two disciplines represent about 50% of the European telemedicine market. The recording of data can be performed simultaneously through one or more channels, depending on the type of the device used.

The objective of the projects in this field is to develop research in order to obtain solutions for the on-line monitoring of patients in a clinic or at home. Thus, the novelty brought by the present paper is to develop a mobile device in order to comfortably collect the ECG data from the patient, to process the ECG signal and to continuously or periodically process the predefined values for each patient and to transmit them to a server [4]. The architecture of the GreenCARDIO system based on the m-GreenCARDIO devices is shown in Fig. 1. One can observe the modules for acquiring and transmitting data corresponding to the ECG measurements, the IoT cloud and the user interface.

The present paper is structured as follows. The first section of this paper contains an introduction to IoT and systems designed to acquire ECG signals, and section II shortly presents projects for remote monitoring of cardiac patients. Section III is dedicated to describe concept and theory of operation of m-GreenCARDIO device, and section IV shows the microcontroller software development, tests and practical results. Section VI presents the final conclusions, contributions by authors and future research directions.

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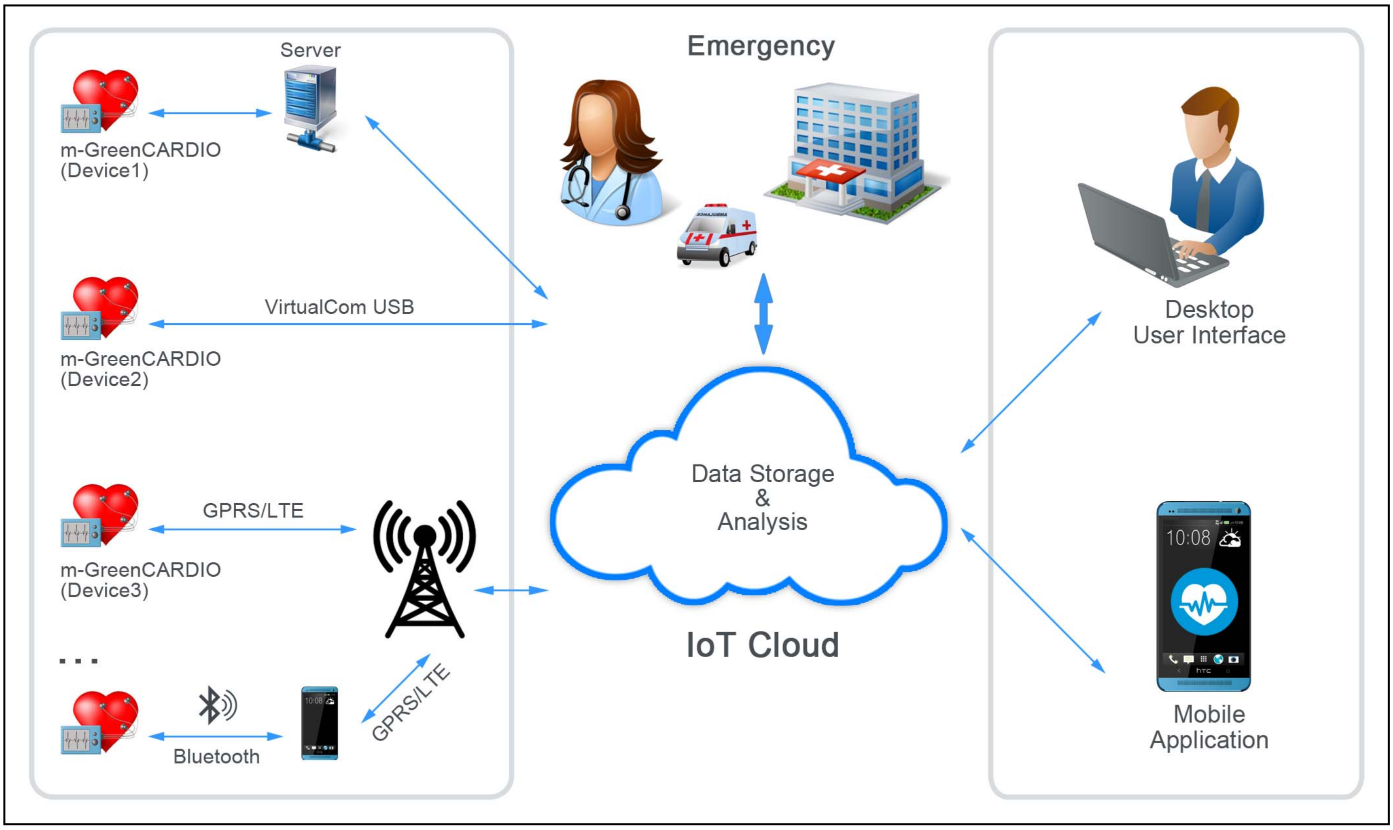


Fig. 1. m-GreenCARDIO system designed for out-of-hospital cardiac patients [5].

II. Related Work

Since the late 80's, telemedicine programs in the field of cardiology are developed in various European countries (Scotland, Greece, France, Sweden, Greenland etc.), but also in the United States hospitals, especially in areas with low population density. In the following part of the paper, we will look at some similar projects that brought significant contribution to this field. We are discussing practical and theoretical aspects regarding the platforms used for implementation, the real time character of the processor and communication interfaces used in the project. The architectures of the considered projects are generally scalable, in relation to the characteristics of the used microcontroller or FPGA. The UART Modules and WiFi enable the serial communication with a PC using a UART/USB (FT232RQ) converter, because most PCs do not have a COM port.

Probably the best known project is EPI-MEDICS [6], performed in collaboration with France-Italy-Sweden researchers (2001-2004); the accomplished aim of the project was the development of a miniature electrocardiograph (personal ECG monitor) with 3 derivates, for the early detection of myocardial ischemia and various aritmies.

The project detailed in [7] presents an implementation based on FPGA for real-time monitoring of cardiac patients. The project uses the FPGA Xilinx SPARTAN-6 XC6SLX16 circuit and the MicroBlaze processor provided by Xilinx. For testing and evaluating the performances of the project, the authors used MIT-BIH Arrhythmia Database [8] and a module based on a Digital to Analog Converter (DAC). The authors use 3 processors implemented in FPGA as follows:

- MB0 processor deals with real-time collection of data from electrodes situated on the patient's body. In the test version, the authors use the signals from the DAC circuit and recordings from MIT-BIH and Arrhythmia Database. This data is sent to the processor 3 (MB2) and to a PC via universal asynchronous receiver transmitter interface (UART) for checking and debugging the system [7]. Thus, using a Visual Basic application running on a PC, the authors convert standard ECG recordings stored in the MIT-BIH database.
- MB1 is second processor implemented in FPGA which deals with tasks that do not require real time response. It implements the user interface (HMI), dealing with the management of switches, LEDs and heart rate display on the 7-segment indicator.
- MB2 is the last processor in the system. It controls and coordinates the MB0 and MB1 slave processors through special functions dedicated to Inter-processors communication FSL interface (transmitting data - *putfsl (date, id)* and receiving data - *getfsl (date, id)*).

The resources needed to implement this project are only 94% of the FPGAs Xilinx Spartan-6 XC6SLX16 resources, because the system is optimized through Hardware/Software

CoDesign techniques [7]. The obtained results are a performance plus in the real-time monitoring of cardiac patients.

In 2016 Ukil et al. discuss the new IoT Healthcare Analytics system as well as the importance of a higher accuracy rate for detecting anomalies [9]. Since the embedded and big data mining systems in healthcare, IoT developed a great deal, and today's systems can offer almost unlimited solutions regarding the analytical predictability in healthcare, accessible remote medical services, as well as an arrhythmia database.

Park et al. use MIT-BIT arrhythmia database for proving that the proposed Wireless system can reach a proper QoS level for real time ECG monitoring, if link-level error control is implemented adequately [10]. The major contributions brought by the authors of this paper refer to providing a flexible QoS assessment framework for wireless healthcare services that can be easily extended to support various networks and mobile devices. On the other hand, the authors argue that they can determine the size of jitter buffer needed to avoid service dropout due to buffer underrun, ensuring an increased reliability in ECG monitoring.

In processors used in mobile applications, such as medical systems and multimedia, the increase of the working frequency is not directly an effective solution, due to increased energy consumption. Thus, by integrating on the same silicon substrate a number of similar computing cores or designing increasingly deeper multithread, hiperthread and pipeline architectures, a more optimal management of the processor time has been enabled. To exemplify, we bring into discussion the ARM Cortex A9 processor family, A15 or A53, although they are also intended for multimedia applications, not only for real-time systems.

Real-time applications run on these multi-core processors, using two, four or eight cores, depending on the performance and power consumption of the mobile applications. An example of this is the Samsung Exynos 8890 Octa representing a System on Chip (SoC) that was announced in 2015 and launched in early 2016 within mobile devices like Galaxy S7. This SoC integrates four Samsung M1 (2.6GHz and 2.3GHz) cores, four ARM Cortex-A53 cores for low power consumption operating at 1.6GHz, an ARM Mali GPU-T880MP12 GPU graphic processing unit (650MHz with a total of 12 cores - MP12, compared to MP4 used in Kirin 950 chipset produced by Huawei) and 2 x 32-bit LPDDR4 (1800 MHz) memory controller. The Octa Samsung Exynos 8890 premium processor, underpinning some of the best 2016 SoC smartphones is made using the 14nm FinFET LPP manufacturing technology that promises a performance increase of 30%.

For applications requiring increased computing power, the processor can use all eight cores in a 64-bit architecture to a maximum frequency of 2.6GHz. The processor may respond positively also in the case of executing small applications, resulting in reduced energy consumption, depending on the tasks running at a given moment on that device, and on the resources of the mobile battery.

In comparison to the implementations based on FPGA [7] that improve the real-time feature by the hardware parallelization of the application's tasks, the m-GreenCARDIO projects described in the present paper is favored by many design and debug tools provided by Keil and ADAS1000 from Analog Devices. m-GreenCARDIO embedded system is designed as a portable device for out-of-hospital cardiac patients.

III. Concept and Theory of Operation

The ECG refers to electrical potentials generated by the heart. The ECG signal is bioelectric with amplitudes in the range of 0.1mV - 2mV when measured at the body surface. The frequency of this signal is in the range of 0.05Hz - 100Hz, although the ECG signal can sometimes have smaller amplitudes, or slightly different frequencies. Therefore, the electrocardiogram is the graphical representation of electrical potential variations, recorded during cardiac activity. Like other tissues, the myocardium generates an electric potential that is transmitted to the skin, varying according to several parameters. This electrical potential can be measured by placing electrodes at certain points on the human body, that result from the recording called an electrocardiogram. The electrocardiograph is the device used to record ECG signals. This instrument comprises the following:

- The signal acquiring system comprising electrodes, connecting wires at the patient and an entry block containing the resistors required for constructing various unipolar derivatives.
- The signal amplification systems.
- The system for displaying, storing and transmitting the signal.

Fig. 2 shows the block diagram of the m-GreenCARDIO device. The bio-potentials generated by living cells and tissues, like all electric currents, are produced by the fact that between two points of an electrical conductor, at a given moment, there is a difference in electrical potential. This difference in potential can be recorded using a galvanometer (an instrument measuring the intensity of a weak electric current).

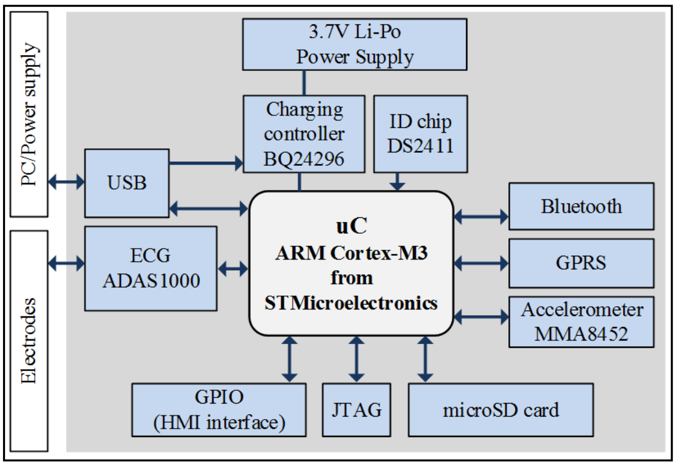


Fig. 2. The block diagram of the m-GreenCARDIO module.

An electrocardiograph is a modified galvanometer that records with high speed the variation of the electrical current generated by the heart; the electrocardiograph amplifies these variations and displays them on a screen or transforms them into mechanical movements in order to print the ECG chart. The main problems that may arise during the acquiring of a ECG signal are the following:

- The technical interferences of the ECG signal.
- The physiological interferences of the ECG signal.

Due to outstanding performances offered by the microcontrollers present on today's market, we can achieve a remarkable flexibility for our application. Thus, the use of pipeline processors, coprocessors, Network on Chip (NoC), and also IoT services, enabled the minimization of the response time and the implementation of innovative projects [11].

Biomedical signal sampling is much more difficult, considering the physiological interferences. To be mentioned that the human body is a complex conglomerate of systems and processes, and many such processes can be active at the same time; the result is the production of several signals of various types. The main electrical parameters are:

- Differential input impedance: 2÷10MΩ/1÷1.5nF.
- Common mode rejection: min. 85dB.
- Input referred noise: 35μV.

The validation of data sent by all chains of wireless transmission and protocol conversion GSM/GPRS/3G/TCP-IP is performed at a segment level and at the level of the communication channel by encapsulating a package and validating the content by the checksum of 32 bit. This procedure enables the integrity confirmation for each data package and, implicitly, of the entire channel.

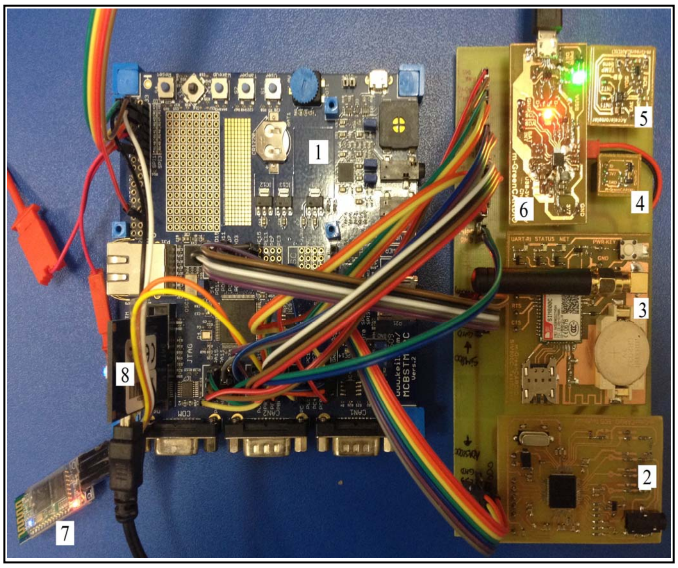


Fig. 3. Testing under laboratory conditions of the m-GreenCARDIO device; 1 - STM32F107 MCU-DEV Board; 2 - ADAS1000 module; 3 - SIM800C-BT module and antenna; 4 – Unique ID module DS2411; 5 - Accelerometer and temperature sensor; 6 - accumulator charger; 7 - Bluetooth, 8 - JTAG.

Increasing the computing power involves mainly increasing the energy consumption – it should be considered that the entire system (battery, wireless mode, 3D mode, general control mode, A/D conversion mode, biomagnification mode and sensors) must not weigh too much, so not to become inconvenient to carry and to ensure a minimum 24 hours autonomy.

IV. Presentation of the Practical Results Obtained During Validation of the m-GreenCARDIO Device

Keil MDK 5 is a suitable environment of Keil ARM Group Company used to create, build, and debug embedded applications. When the difficulty of the applications increases, the designer code has to control more and more concurrent jobs and it becomes difficult to ensure that such applications run safely without an embedded OS. In this project, we are using a typical embedded OS called Real-Time Executive (RTX) kernel. Part of the embedded OS is called Real-Time Operating Systems (RTOS), and it provides both a predictable answer in a defined time period, and a very fast context switching time.

The application has been developed by using the MCBSTM32C development board with the STM32F107 microcontroller compatible pin-wise with the microcontroller chosen for the tele-ECG mobile (32L151), and the modules that are presented in Fig. 3.

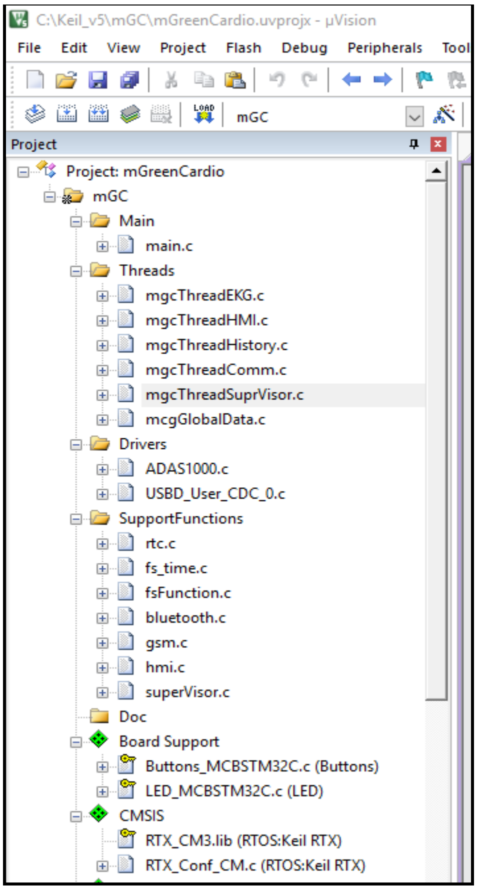


Fig. 4. Application structure for the tele-ECG device in Keil uVision5.

In order to acquire data, the processor is configured to execute the task 0 with a periodicity of 10ms (100Hz) for reading the ECG signal samples. The Serial Peripheral Interface (SPI) between the processor and the ECG chip performs serial transmission of digital data supplied by Analog to Digital Converter (ADC) on the ECG module.

In current embedded systems, the approach of such a project, using designs based on a single processor, is an advantage in terms of the reduced energy consumption. Although real-time tasks used for data acquisition are in small numbers, the complexity of the system can not be greatly increased, as situations of unpredictability are completely eliminated. The difference between Cortex-M and Cortex-A microcontroller is that the last one has a Memory Management Unit (MMU) for remapping logical address to physical address [12], which is necessary for Linux operations. Cortex-M cannot have a virtual address support to run a full-feature Linux system, but it has a valuable Memory Protection Unit (MPU). The MMU does not introduce additional delays, guaranteeing a predictable response time for many real-time applications that use Cortex-M processors.

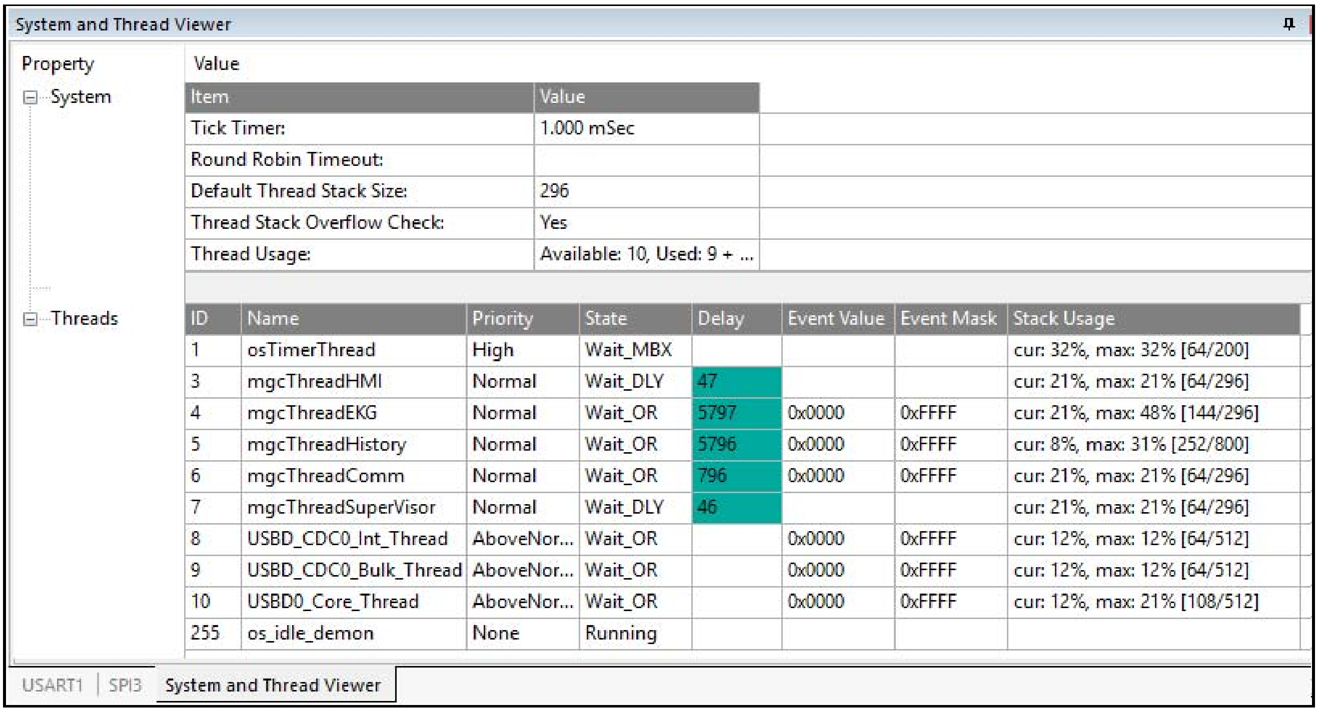
The processing of signals acquired from people on the move is also an important objective for projects in this area [13]. Thus, various solutions attempt to filter the disturbances caused by the patient's movement or by the changes in the environment in which the patient is (underground, systems with strong perturbing induction or fluorescent lighting).

We present below some activities performed in the design and design procedure. Fig. 4 shows *mGC* project structure, the organization of the application for the tele-ECG mobile device, from the point of view of the MDK 5.21a development environment. MDK 5.21a from Keil uVision 5 features a powerful debugger which includes, among others, the step-by-step running of programs breakpoints, for both program and data codes, support for the operation system, as well as for the function editor [14]. The microcontroller is used from the low-power family, so the total current consumption will be approx. 43mA.

The SPI interface between the microcontroller and the ADAS1000 circuit performs data exchange in both directions simultaneously, supporting a single master communication with multiple slave devices. The clock frequency determines the data transfer rate, that is normally between 100KHz to 10MHz, implying that the data rate ranges from 1 to 20 Mbps. The many projects representing various Hardware/Software implementations have lead to scalable projects, greater flexibility in production and a decrease in time-to-market time.

For proper function, the ADAS1000 ECG circuit will need a total current consumption of 17.3mA. This is the maximum value needed, when used three electrodes and the respiration module is activated. The low-power Bluetooth module will consume only 10.5mA in transmission mode and 3.5µA in system idle mode.

From the point of view of the RTOS configuration, all tasks of the application are on, as shown in Fig. 5. The design environment also provides solid support for memory viewing, variables watching, event viewing, tracking and modifying peripheral registers; it also provides an efficient logic analyzer, various viewing windows (symbols, stack, serial communication, etc.) that enable, in addition to testing in real-life conditions, logical testing both by simulation and by forcing values. Using this support, a special code was written in the design and debug stage to test the functionality of some procedures under laboratory conditions.



System and Thread Viewer

Property: System

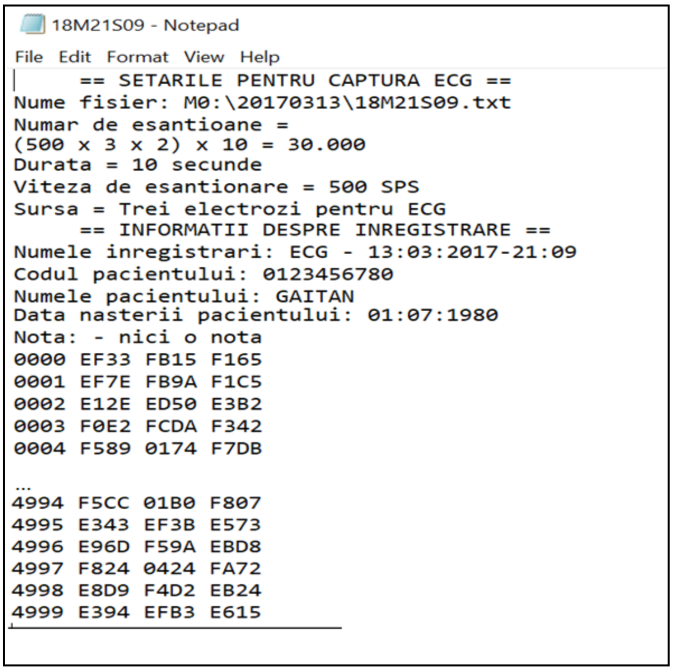
Item	Value
Tick Timer:	1.000 mSec
Round Robin Timeout:	
Default Thread Stack Size:	296
Thread Stack Overflow Check:	Yes
Thread Usage:	Available: 10, Used: 9 + ...

Property: Threads

ID	Name	Priority	State	Delay	Event Value	Event Mask	Stack Usage
1	osTimerThread	High	Wait_MBX				cur: 32%, max: 32% [64/200]
3	mgcThreadHMI	Normal	Wait_DLY	47			cur: 21%, max: 21% [64/296]
4	mgcThreadEKG	Normal	Wait_OR	5797	0x0000	0xFFFF	cur: 21%, max: 48% [144/296]
5	mgcThreadHistory	Normal	Wait_OR	5796	0x0000	0xFFFF	cur: 8%, max: 31% [252/800]
6	mgcThreadComm	Normal	Wait_OR	796	0x0000	0xFFFF	cur: 21%, max: 21% [64/296]
7	mgcThreadSuperVisor	Normal	Wait_DLY	46			cur: 21%, max: 21% [64/296]
8	USBD_CDC0_Int_Thread	AboveNor...	Wait_OR		0x0000	0xFFFF	cur: 12%, max: 12% [64/512]
9	USBD_CDC0_Bulk_Thread	AboveNor...	Wait_OR		0x0000	0xFFFF	cur: 12%, max: 12% [64/512]
10	USBD0_Core_Thread	AboveNor...	Wait_OR		0x0000	0xFFFF	cur: 12%, max: 21% [108/512]
255	os_idle_demon	None	Running				

USART1 | SPI3 | System and Thread Viewer

Fig. 5. The installed application tasks seen in uVision5 DEBUG mode (the application is already running on the microcontroller).



18M21S09 - Notepad

File Edit Format View Help

```
      == SETARILE PENTRU CAPTURA ECG ==
Nume fisier: M0:\20170313\18M21S09.txt
Numar de esantioane =
(500 x 3 x 2) x 10 = 30.000
Durata = 10 secunde
Viteza de esantionare = 500 SPS
Sursa = Trei electrozi pentru ECG
      == INFORMATII DESPRE INREGISTRARE ==
Numele inregistrari: ECG - 13:03:2017-21:09
Codul pacientului: 0123456780
Numele pacientului: GAITAN
Data nasterii pacientului: 01:07:1980
Nota: - nici o nota
0000 EF33 FB15 F165
0001 EF7E FB9A F1C5
0002 E12E ED50 E3B2
0003 F0E2 FCDA F342
0004 F589 0174 F7DB

...
4994 F5CC 01B0 F807
4995 E343 EF3B E573
4996 E96D F59A EBD8
4997 F824 0424 FA72
4998 E8D9 F4D2 EB24
4999 E394 EFB3 E615
```

Fig. 6. Structure of an ASCII ECG file with 5000 records for 3 electrodes.

Fig. 6 shows the structure of an ECG file, the operations of managing these files being performed by the *mgcThread History* task at the initiative of the *mgcThreadComm* task. Saving the ECG on the SD card as a file is done by the *mgcThreadHistory* task, when receiving an event from the *mgcThreadEKG* task. In the design and testing stages of the microcontroller software, it was necessary to configure various tests as well as to write code for the extra MODBUS functions used to trigger the launch of complex test operations. The main tests for the mobile tele-ECG application and their tasks are presented below, with a highlight on the operation and the tasks involved. After the RTOS task setup stage, a user interface has been developed, namely handling the event generated by the action on the user button, by using the wake up key on the MCBST32C kit (*mgcThreadHMI* task). In addition to the user interface, LEDs were turned on and sound was generated using the buzzer (*mgcThreadHMI* task). The *mgcThreadComm* task is responsible for the implementation of communication components, namely: USB and VitualComm (PC) communication using Modbus Poll, Bluetooth communication with HC 06 and GSM/SMS communication via SIM800 circuit (SMS have been tested with the phone mobile). In addition to these actions, the DEBUG module has been activated; by this module, the *mgcThreadComm* task can simulate all the MODBUS messages of the other tasks. For hardware debugging, the following have been tested: the reading/writing of ADAS100 circuit boards (*mgcThreadEKG* enabled by *mgcThreadComm* task), the ECG release (*mgcThreadEKG* task launched by either *mgcThreadHMI* or *mgcThreadComm* tasks as a result of an extra function), the reading of files on SD card (the *mgcThreadHistory* task at the initiative of the *mgcThreadComm* task), the WDT circuit operation, the temperature sensor accelerometer and the battery charging and supervision circuit (*mgcThreadSuperVisor* task). Fig. 7 plots part of the ECG signal collected from a person using MATLAB R2017b. For real-time testing, MODBUS (TCR-MD) functions have often been used. Thus, Modbus 42 extra-function launches the execution of a ECG (it activates the *EVT_EXECUTED_BY _EKG_TO_COMM* event for announcing the communication task that is to be executed), and afterwards performs the ECG. If ECG is properly executed, it sends an *EVT_EXE_EKG_ LOGG_NEW_JOB* event for the history task to save the ECG as an ASCII file on the SD card.

GreenCardio is a telemedicine application that represents a link between the general practitioner and the cardiologist, which favors the possibility of "remote" interpretation of electrocardiograms for patients in the rural area [15]. The beneficiaries of this system are patients living in rural areas, patients that can't be transported, or patients that want to see their medical status without going to the specialist.

Compared to other similar projects related in literature [7], [9], m-GreenCARDIO device performs the saving of the ECG data on a microSD, from where it can be retrieved later, if there is no functional communication when the ECG is performed. Using STM32F107 microcontroller would add extra performance to the system because, besides the flexibility, it also ensures a low power consumption. In the case of m-GreenCARDIO, heart rate storing and transmitting the data to a supervisor are the core objectives of the system. Therefore, the data collected by the proposed m-GreenCARDIO embedded system designed for out-of-hospital cardiac patients satisfy both the accuracy and reliability requirements.

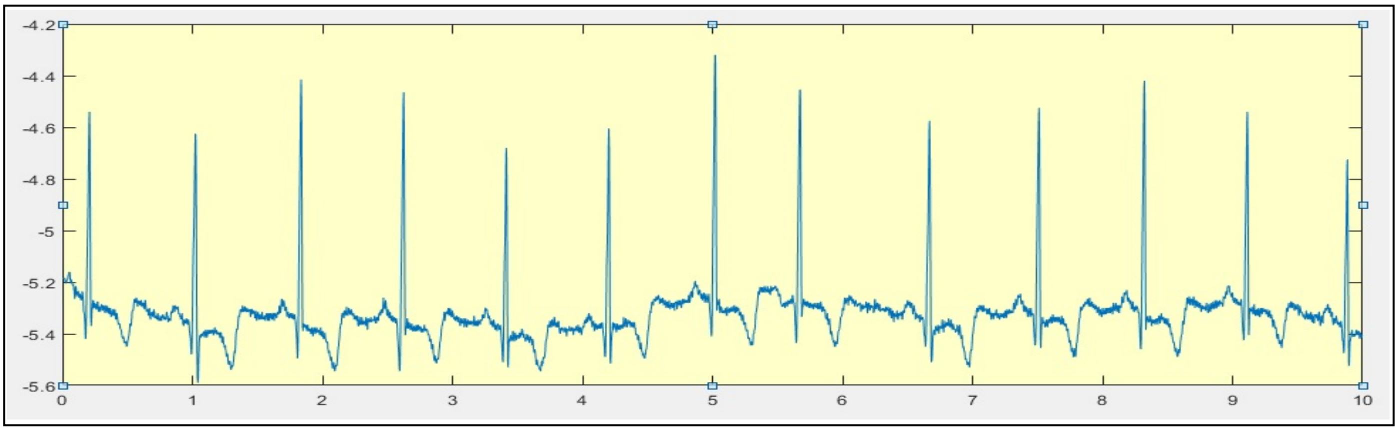


Fig. 7. The ECG signal using the MATLAB R2017b.

A competitive monitoring system must detect in real time the signal's pathological abnormalities. Such a system has the following functions:

- The continuous ECG acquisition on multiple channels.
- Real-time signal preprocessing. Low-pass median filters, adaptive filtering or 50Hz rejection filter can be used.
- Real-time assessment of signal/noise ratio for different frequency bands, in order to determine the nature of the noise.
- Dynamic selection of the optimal noise extractor and of the QRS complex detector.
- Alarm in case of critical situations and data storage in the absence of communication.
- Secure data interpretation for diagnosis assistance.
- Transmission of synthetic data to high level module, to detect and classify various pathologies by using pattern recognition methods.

V. Conclusion and Future Work

Designing tools for remote and real-time monitoring of out-of-hospital cardiac patient is a novelty in the field and a real challenge in the IoT context. The MCBSTM32 kit and Keil development platform were essential in facilitating our research activity for designing, prototyping and testing the mobile tele-electrocardiograph within the GreenCARDIO system for monitoring and diagnosis of patients. In case predefined critical elements appear, the specialized GreenCARDIO server notifies the dispatcher about the event. Consequently, it is important that the finished research project written and implemented in C source code is well documented, flexible and parameterized.

The challenge of the m-GreenCARDIO embedded system designed for out-of-hospital cardiac patients is achieved through compliance with the strict rules imposed in the field of medical devices, which is not always easy to achieve because a lot of practical experience are required. As a result, we were able to demonstrate the potential of the technologies used by designing a m-GreenCARDIO competitive device to meet the needs and requirements demanded by the market, minimizing design time due to rapid prototyping and testing. m-GreenCARDIO embedded device can be optimised by improving the software, energy consumption and overall IoT system performances.

Acknowledgment

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References

[1] V. Madisetti and A. Bahga, “Internet of Things (A Hands-on-Approach),” pp. 20–46, Aug. 2014. ISBN-10:0996025510, ISBN-13:978-0996025515.

[2] I. Ungurean, N. C. Găitan, and V. G. Găitan, “An IoT architecture for things from industrial environment,” 10th International Conference on Communications (COMM), Bucharest, pp. 1–4, May 2014. doi: 10.1109/ICComm.2014.6866713.

[3] G. Corotinschi, V. G. Găitan, “The development of IoT applications using old hardware equipment and virtual TEDS,” in 13rt International Conference on Development and Application Systems – DAS, Suceava, Romania, pp. 264–268, May 2016. doi: 10.1109/DAAS.2016.7492584.

[4] I. Ungurean, A. Brezulianu, “An Internet of Things Framework for Remote Monitoring of the HealthCare Parameters,” Advances in Electrical and Computer Engineering, vol. 17, no. 2, pp. 11–16, 2017, doi:10.4316/AECE.2017.02002.

[5] I. Zagan, V. G. Gaitan, A.-I. Petrariu, A. Brezulianu, “Healthcare IoT m-GreenCARDIO Remote Cardiac Monitoring System - Concept, Theory of Operation and Implementation,” Advances in Electrical and Computer Engineering, vol.17, no.2, pp. 23–30, 2017, doi:10.4316/AECE.2017.02004.

[6] F. Gouaux et al., “Ambient intelligence and pervasive systems for the monitoring of citizens at cardiac risk: New solutions from the EPI-MEDICS project,” Computers in Cardiology, 2002, pp. 289–292. doi: 10.1109/CIC.2002.1166765

[7] E. H. El Mimouni and M. Karim, “A MicroBlaze-based Multiprocessor System on Chip for real-time cardiac monitoring,” 2014 International Conference on Multimedia Computing and Systems (ICMCS), Marrakech, pp. 331–336, Apr. 2014. doi: 10.1109/ICMCS.2014.6911414.

[8] https://physionet.org/physiobank/database/mitdb/, (Accessed: Mar. 2017).

[9] A. Ukil, S. Bandyoapdhyay, C. Puri and A. Pal, “IoT Healthcare Analytics: The Importance of Anomaly Detection,” 2016 IEEE 30th International Conference on Advanced Information Networking and Applications (AINA), Crans-Montana, 2016, pp. 994–997. doi: 10.1109/AINA.2016.158.

[10] J. Park, J. Lee, J. Ryu, H. Shin, S. Heu and K. Kang, “Evaluating QoS of a Wireless System for Real-Time Cardiac Monitoring,” 2013 IEEE 27th International Conference on Advanced Information Networking and Applications (AINA), Barcelona, 2013, pp. 1105–1112. doi: 10.1109/AINA.2013.62.

[11] Z. Yang, Q. Zhou, L. Lei, K. Zheng, W. Xiang, “An IoT-cloud Based Wearable ECG Monitoring System for Smart Healthcare,” Journal of Medical Systems (2016) 40: 286, Springer US, ISSN: 0148-5598, 2016, https://doi.org/10.1007/s10916-016-0644-9.

[12] J. Yiu, “The Definitive Guide to ARM® Cortex®-M0 and Cortex-M0+ Processors,” 2nd Edition, pp. 57–64, Jun. 2015. ISBN-10: 0128032774.

[13] C. Hariton, “ELECTRONICĂ MEDICALĂ,” cap. 1, http://www.umfiasi.ro/masterate/Suporturi%20de%20curs/Facultatea%20de%20Bioinginerie/Curs%20Electronica%20Medicala,%20an%20III/Cap1_prez_analiza_ECG.pdf, (Accessed: Mar. 2018).

[14] Y. Zhu, “Embedded Systems with ARM Cortex-M3 Microcontrollers in Assembly Language and C,” pp. 457–464, Aug. 2014. ISBN-10: 0982692625, ISBN-13: 978-0982692622.

[15] http://www.greensoft.com.ro/, (Accessed: Apr. 2018).