Healthcare IoT m-GreenCARDIO Remote Cardiac Monitoring System – Concept, Theory of Operation and Implementation

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***Abstract*—Present day Internet of Things (IoT) developers are inspired by the spectacular evolution in the field, and, at the same time, determined to connect an increasingly wider range of „things", with the lowest power consumption, the wider range of action and interoperability guaranteed with excessive quality. Based on current challenges in the medical and electronic field, the present paper seeks the practical implementation of an efficient, low cost, low-power IoT medical system, yet with a greater memory autonomy. In this context, our main contribution is the implementation of a solution for ECG monitoring based on IoT techniques. This paper presents a qualitative research in the field of healthcare IoT and embedded applications meant to provide an innovative and flexible system meeting the stringent requirements of this area. Without compromising the performance intake and the low power consumption, the designers offer flexible options for connectivity and response time.**

***Index Terms*—internet of things, microcontrollers, personal area networks, public healthcare, bluetooth.**

I. Introduction

The implementation of wireless connections by pre-certified modules may be the simplest solution for using the IoT. As long as it evolves, the implementation of IoT is open to interpretation and can comprise projects of any size. Therefore, IoT is a massive opportunity, as it represents a market that is expected to be worth trillions in a few decades. The current research in this field represents an important factor in the rapid extension of IoT and in the medical field for creating new models based on current approaches. The complete exploitation of IoT strategies requires much more than the local use of an electrocardiogram (ECG) sensor by the microcontroller. It requires a software, an ecosystem of hardware and services; during cohabitation, they will create a closed loop able to provide eloquent perspectives in health care and beyond.

An IoT space will contain numerous elements offering a connectivity platform consisting of hardware, software that could include an operating system, cloud-based services and management tools [1]. Their role is to collect data, to store and transfer them, to obtain partial or final results and to take actions in response to those results [2].

To the extent that the microcontroller and the ECG sensors offer the capability to collect the required parameters, the connectivity is that providing a reaction in an IoT working environment. In a continuously increasing number of applications in this field, wireless connectivity is confirmed to provide notable advantages of which the most important is the flexibility rendered by the lack of a physical connection.

Most wireless protocols were designed to provide flexibility, security, robustness, and also to be easy to integrate in the final applications designed to operate in any environment. Due to the growth in the consumer sector, the hardware necessary to implement a wireless connection is now available at irresistibly small prices, enabling the device designers in any field to develop increasingly complex applications.

The purpose of IoT is not limited only to connecting things to the Internet, but to enable them to communicate or exchange information regarding state and control [3]. The IoT projects cover a wide range of areas, such as health, industry, homes, energy systems, logistics or environment. Fig. 1 shows the generic block diagram of a single-board computer (SBC) based IoT device.

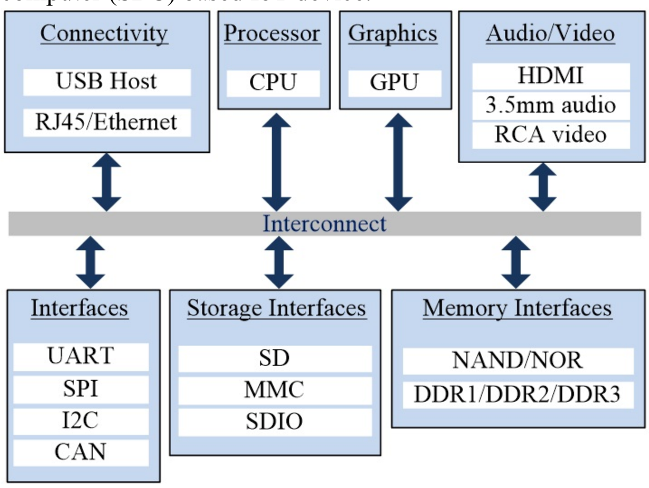

Figure 1. The block diagram of a IoT cyber-physical system (CPS) [3]

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By using a service platform, an IoT developer can focus more on the logical design of the application, thus adding value to the final project. An IoT service platform provides the designers with tools and interfaces to quickly host, administer and monitor the services. It also provides a suitable architecture and hardware abstraction model, appropriate for communication over a wide variety of protocols [4].

The present paper is structured as follows. The first section is a brief introduction based on the IoT development practices. Section II addresses other similar projects published in the literature and section III shows a block diagram of the m-GreenCARDIO project for remote monitoring of cardiac patients. Section IV is dedicated to the design and implementation of real-time embedded system for obtaining the ECG. Based on these tests and preliminary results, in section V is described the software architecture and thread organization. Section VI completes the article with final conclusions, emphasizing the contributions of the authors.

II. Related Work

In this chapter we are presenting and describing the most important projects proposed in the field literature, that have made a strong impact on research in the field of IoT and that of real time monitoring of cardiac patients.

In Poland, the telemetry system of the ECG signal began to be developed in 1996 and currently the hospitalization ratio of cardiovascular patients has been reduced from 5% to 2%. The system started by involving 2000 individual patients and over 12000 patients from family physicians, the ECG signals database containing over 22500 recordings.

In Osaka, Japan, the efficiency of the Tele-ECG transmission has led to the decrease by 57% of cardiopulmonary arrest patients, through their detection and rapid intervention.

In [5], the authors present a hardware module based on FPGA for real-time monitoring of cardiac persons. The Multiprocessor System on Chip (MPSoC) project is based on three processors implemented using Xilinx soft processor MicroBlaze and the FPGA Xilinx SPARTAN-6 XC6SLX16 circuit. The first processor, named MB0, has been used for real-time processing of signals generated by the electrodes placed on the patient's body or from the DAC circuit used for the test. MB0 achieved both QRS detection and the heart rate calculation. The second processor implemented in FPGA is named MB1 and deals with the tasks that do not require a response time characteristic to real-time systems. The last processor, named MB2, performs the master function for the first two processors. The practical results, obtained by the authors in implementing the present project, bring an important contribution to the field from the point of view of the obtaining an ECG by using a real-time processor. The fact that recordings from MIT-BIH Arrhythmia Database [6] have been used proves that the implementation of MPSoC has been tested on a wide range of ECG signals. The disadvantage of the present project is that the data represented by the ECG, QRS detection and heart rate, obtained in real time, are not stored in a local memory or sent to a data server to be used and analyzed later.

In [7], the authors propose a platform that allows the plug-in operation and remote control of multi-vendor medical devices. The project is focused on the electronic stethoscope and 12-lead ECG that allows short-term cardiac monitoring. When the coverage area cannot be guaranteed and the real-time functionality is not provided, the solution chosen by the authors is to delay the transmission of data.

Yang et all. propose a new method for ECG monitoring based on IoT [8]. The system is based on ECG Sensing Network, which is responsible for collecting and transmitting ECG data to the IoT cloud through a wireless channel. Using the IoT cloud, the ECG data is stored and analyzed. The GUI provide easy access to the data in the IoT cloud, supporting mobile apps and webpages. Also, the authors pay close attention to the real time characteristic of the system, the real-time ECG signals being collected with satisfactory precision.

The project leaves room for further research in order to improve and optimize the diagnosis module regarding possible cardiac conditions.

In [9] the authors present the implementation of fog computing services, including interoperability, real-time notification system, location awareness, HMI and distributed database. The system proposed in this paper is efficient in terms of transmission latency minimization, reducing the number of data transmitted over a network. Therefore, the volume of transmitted data is significantly reduced, and users can access in real time the required data through a gateway graphical user interface.

In [10] the authors propose a new system for real-time and remote monitoring of out-of-hospital patients, especially people with heart diseases. To provide more convenient, efficient and comprehensive medical monitoring, the authors present a portable terminal device able to interact with the central monitoring system of the hospital. The project is based on an ARM9 microcontroller, an ECG acquisition module, a GPRS-GPS module, HMI and a battery together with the management of its. The system performance enabled simultaneous monitoring of multiple cardiac patients with a high risk of stroke. Since ECG analysis is performed in real time, the authors assert that the proposed module, that integrates a system for GPS positioning, brings extra safety and shortens the time of intervention in the cases of the patients concerned. Because doctors have easy access to the patient's medical condition, authors aim to extend this device for monitoring body temperature, blood pressure and other parameters.

III. Describing the ECG Monitoring System based on m-GreenCARDIO and Healthcare IoT

The current research in the field of IoT [11-12], the idea for implementing this project, as well as the embedded systems, were important factors in designing a mobile tele-electrocardiograph (m-GreenCARDIO) in the GreenCARDIO monitoring and diagnosing system for cardiac patients [13].

The architecture of the ECG monitoring system based on the healthcare IoT concept and the m-GreenCARDIO module is shown in Fig. 2. One can observe the modules for acquiring and transmitting data corresponding to the ECG measurements, the IoT cloud and the user interface.

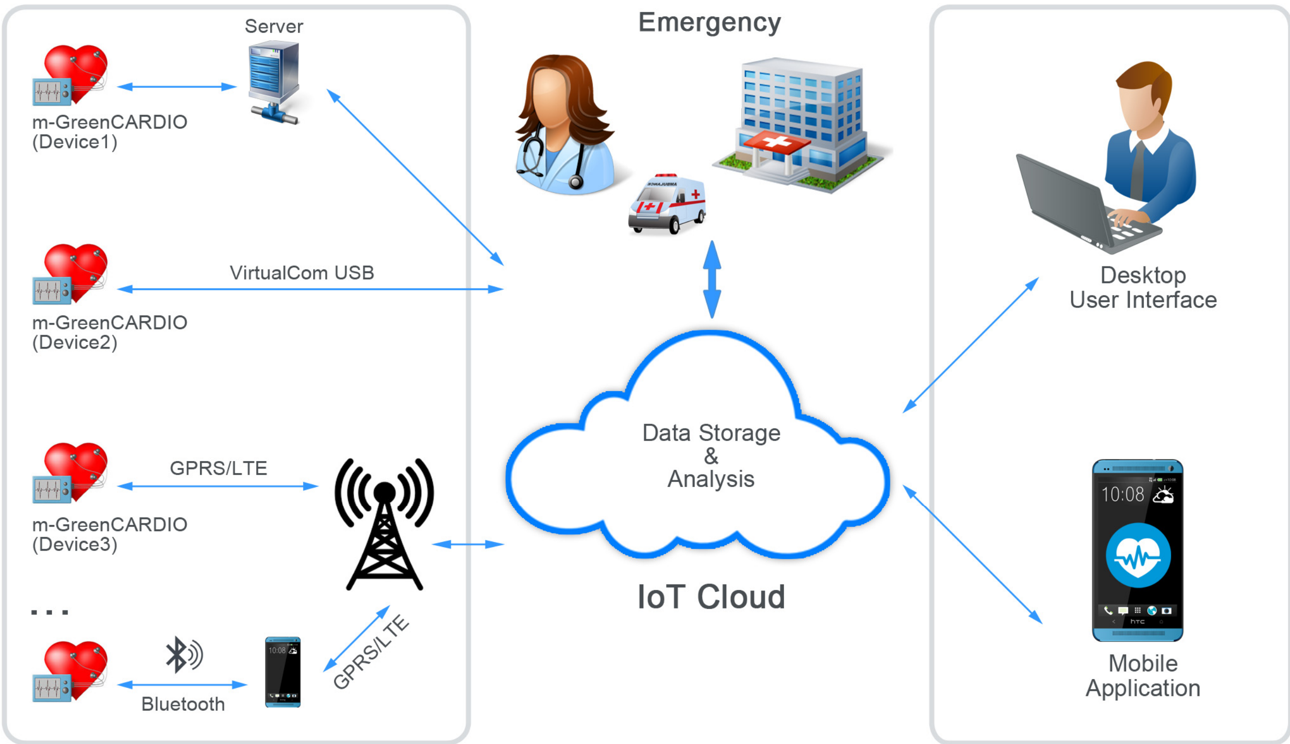

Figure 2. The diagram for the ECG monitoring system based on the m-GreenCARDIO module and healthcare IoT

Based on theoretical and practical studies regarding the implementation of an ECG, the basic requirements for implementing the m-GreenCARDIO mobile device are the following: high precision and accuracy; small size (the aim is that the weight of the device does not exceed 100 grams); the ECG investigation result is stored on a microSD card and it is sent automatically and immediately, via a wireless network, to an application running on a mobile phone, laptop or PC; it uses rechargeable batteries that can be recharged using a micro USB connector; an accelerometer will be attached in order to validate the correct position of the patient; communication with other wireless systems will be performed via Bluetooth and GSM/GPRS and optionally, via a wired USB; the housing will be provided with a button and three (five) LED indicators and it should be easy to handle; It will also be provided with three electrodes, digital filtering and will use a special ECG chip.

In the context of the related work, the novelty brought by the present article is the implementation of a healthcare IoT device with a local microSD memory and multiple communication interfaces in order to diagnose remotely and in real time patients with heart disease. This allows the expansion of ECG investigations capabilities by patients who cannot receive specialty medical services in the field of cardiology, such as patients from rural area, unmovable patients and those who want to be able to investigate their medical status without visiting the doctor.

The project deals with monitoring cardiac patients based on the electrocardiogram signal, ECG being one of the most commonly used instruments in medical practice, due to its non-invasive nature, the simplicity of the signal acquisition process, as well as the significant information it contains. The analysis of these information enables the evaluation of the heart state [14], so that the ECG allows the cardiac monitoring of patients in real time and in secure conditions in terms of the information provided by these signals [15]. This is a standard practice used in intensive care, emergency rooms, mobile interventions and other places of monitoring and control. As long as Wi-Fi is a reliable wireless solution to Ethernet/LAN connectivity, the technology behind the Personal Area Networks is based on wireless network technology such as: Bluetooth, ZigBee (2.4Ghz) or Z-Wave. Bluetooth 4.0 (BLE) has a low power consumption and provides a standard solution for establishing a peer-to-peer wireless connection or custom designed networks for short distances. This is especially suited for applications where data are collected periodically, for example, in the design of a wearable ECG terminal. Also, for medical wireless connections, MICS - Medical Implant Communications Service (402-405MHz) or WMTS - Wireless Medical Telemetry Service (608-614Mhz) can be used. For implementation reasons, from the solutions mentioned above, only Bluetooth and Zigbee are truly practical solutions, providing the possibility of using commercial chips at competitive prices. The designing of this embedded system has been guided by the current hardware/software approaches, aiming to optimize and meet the constraints of designing a final product in the medical field. As far as the hardware resources and the developing tools for designing and validating the test product are concerned, we can mention the following: the ST development kit, the ECG chip, the Bluetooth chip - the size of the module and the low power consumption - have been specially designed for wearable applications; VirtualComm, GSM/GPRS transmitter have been designed for transmitting data [16], and the Keil design environment, RTOS operation system, Altium Designer environment for designing the hardware prototype and subsequently the final project and the PicoScope oscilloscope to view the signals transmitted and received by each module used in the design.

IV. Hardware Design of the m-GreenCARDIO

A. General description of the architecture

m-GreenCARDIO system is designed as a portable device. Thus, they are needed some modules to make it wearable and usable for various type of patients. The main block components of the system are mentioned in Fig. 3 and are as follows:

- ***uC (microcontroller)*** used for processing the collected ECG data. The microcontroller used is from the family STM32F107 and is a powerful one built on ARM Cortex-M3 from STMicroelectronics. It has 256kB of FLASH memory and 64k of RAM, which are enough because the whole system is optimized to require only few resources. The microcontroller is used from the low-power family, so the total current consumption will be approx. 43mA (having activated the needed peripherals) in normal mode and 3.8μA in sleep mode, with the code running from RAM. The project offers the elements for a complete healthcare IoT solution for applications in the medical field. In the case of processors in the field of mobile applications, by using processor architectures such as ARM, a more optimal management of processor time has been enabled without increasing too much the power consumption. The first ARM SoC that supported the ARM architecture in coreboot was Samsung Exynos 5250, which was seen as a successful experimental proof of the concept [17]. The microcontroller is mounted to an adapter board (Fig. 4) and can be changed by the future developers of the m-GreenCARDIO system in case if this type of the microcontroller is obsolete. In this case all the pins can be configurable to match the main board of the system.
- ***ECG circuit*** linked to a standard ECG interface. The dedicated circuit measures the ECG signal via the electrodes placed on the surface of the body, using a standard DB15 female connector. This connector provides the primary analog input interface to which customer proprietary lead sets are connected. Thus, the heart's electric activity is monitored through a potential difference with a maximum amplitude of 1mV and a band-width from 0.05Hz to 100Hz. An ECG signal is characterized mainly by 5 waves per interval R-R, these being named P, Q, R, S and T. In the process of acquiring medical signals, there is the risk that the useful information collected from the patient is altered by certain interferences induced by the instrumentation amplifier, by the system for recording signals, or by the electromagnetic waves generated by other electronic devices; in most cases, the noise from the electrical network and the harmonics of this disturbing signal are added to those aforementioned. Thus, the 50/60Hz interference generated by the 230V power supply and propagate through AC-DC converters is considered a high frequency disturbing device, if we take into account the ECG low frequency signal spectra (up to 100Hz). The cable shielding, grounding of the enclosure and using suitable filters, reduces significantly the possibility of electromagnetic interferences (EMI) caused by the power supply frequency (50Hz and 60Hz). For example, the bandwidth of interest for the ECG signal is between 0.05Hz and 100Hz, but also includes the 50Hz and 60Hz component. Thus, the simple filtering with a drop-down filter is not viable, and the signal filtering with a band-pass filter under 50/60Hz can smooth the QRS complex, altering also the PQ and ST segments. Therefore, the ideal solution for filtering the ECG signal is the removal of the 50/60Hz component, without affecting the other signal components. For the ECG circuit is used ADAS1000 from Analog Devices.

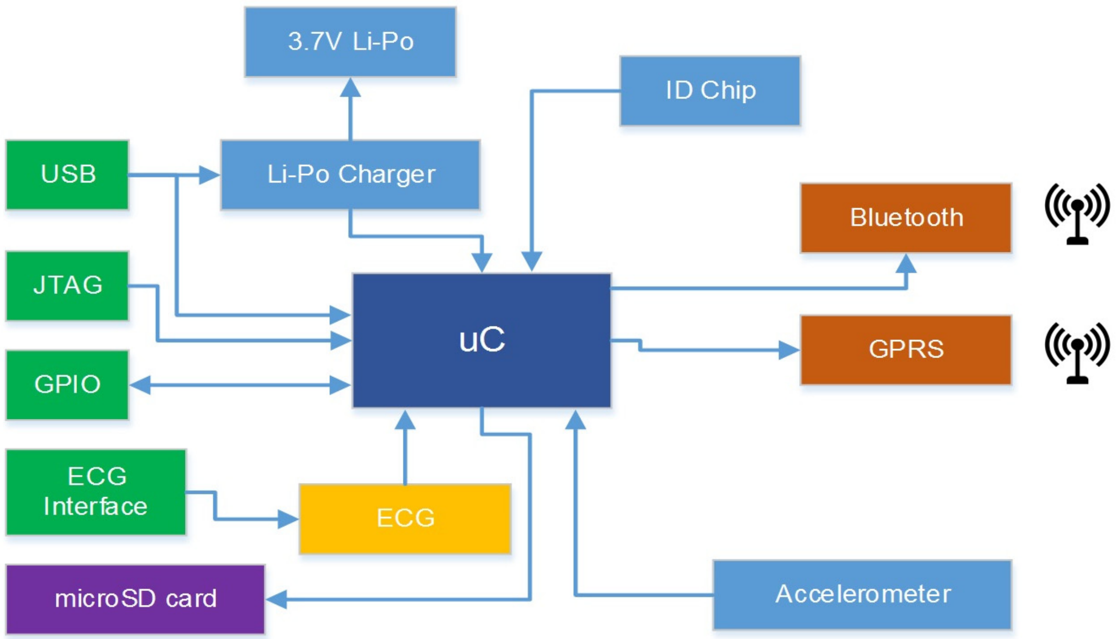

Figure 3. The hardware architecture of the m-GreenCARDIO module

The IC provides good filtering of the ECG signals to ensure high quality received data from the monitored patient. For proper function, the mentioned IC 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 communication with the microcontroller is made using the standard SPI interface. The characteristics of this IC are proper for using it in the proposed ECG system due to its functions.

- ***microSD card*** used for saving the collected data. Before displaying all the information's into an application or send them to the IoT cloud server, the ECG data are stored into a microSD card as text files or XML. In case if the communication module isn't transmitting the collected data, the device has the possibility to send them after the connection is established with the application or the IoT cloud server. If we take into account using a standard microSD card, then will be need a total of 100mA current consumption for read/write operation and only 350μA when it's in sleep mode.
- ***Accelerometer*** used for ensure three-axis position status of the m-GreenCARDIO system linked to a standard ECG interface. The accelerometer will get the position of the device and will inform the patient the correct position of the body in order to ensure the right readings of ECG signals. For best results, the patient must lie down, still and breathe normally. Sometimes for accurate results the patient need to hold his breath for few seconds. An ECG can lasts about 5 to 10 minutes. In some cases, this period may be extended, for example, when measuring heart rate. As accelerometer is used MMA8452, a low-power MEMS, with 12 bit resolution [18]. The IC can generate inertial wakeup interrupt signals and stay in low-power mode when isn't use. This IC needs for proper function only 24μA when is running in normal mode (with 50Hz acquisition frequency) and 14μA when is used in low-power mode (with the same 50Hz acquisition frequency). In standby mode, the IC will need only 4μA as current consumption.
- ***ID Chip*** used to ensure unique ID of the system. As the ID Chip is used DS2411 which will give a factory-lasered 64-bit registration number to each device [19]. In this case, every portable m-GreenCARDIO device will be linked only to one patient, avoiding wrong allocation of transmitted data to another cardiac patient. To provide required information, the IC will need a total of 100μA and 1μA in standby mode.
- ***Bluetooth*** used to transmit the collected data to a mobile application. Every patient can monitor by itself the health using a mobile application installed on a smartphone or a tablet. The application will send automatically the collected data to an IoT cloud server, from where a medical personnel can see the evolution of the patient. In case if the health condition of the patient it's getting worse, the medical personnel will inform a first aid unit and the patient can be saved.

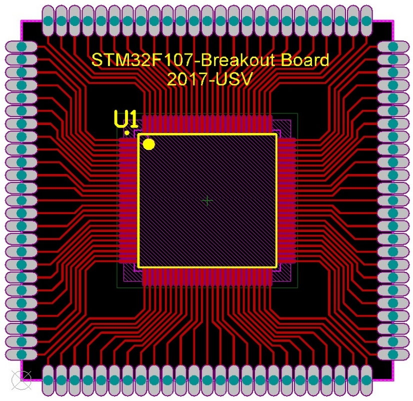

Figure 4. Adapter board of the microcontroller

For the m-GreenCARDIO system is used a low-power Bluetooth module, that will consume only 10.5mA in TX mode with a transmitted power of 0dBm and 3.5μA in standby or system idle mode.

- ***GPRS module*** used to transmit the collected data directly to a cloud IoT server. This type of module is suitable for cases when the patient hasn't a smartphone or a tablet, and the data are transmitted directly in cloud, from where can be analyzed by the medical personnel. This module is also suitable for ambulances or first aid units. This is the largest power consumer module, with a value of 450mA in TX mode and 30μA in standby mode. This module is used only in special cases, as mentioned above.
- ***3.7V Li-Po*** rechargeable battery, with a total capacity of 2500mA that will ensure multiple readings of the ECG signals and transmit them to a data storage and analysis cloud IoT server.
- ***Li-Po charger*** for the device rechargeable battery. All system is powered through a 3.7V Li-Po rechargeable battery which can be charged from an USB port. The charging controller used (BQ24296) from Texas Instrument will provide to the user via the GUI from the mobile phone the exact status of the battery and when need to be charged [20]. All the information's are send to the microcontroller via I2C interface. The IC will provide 2 charging modes for the battery using a PSEL pin, depending on the USB power source: standard mode and fast charging mode. This will help protect the battery with different charging algorithms and extends the battery lifetime. In standard mode the IC will sense if the USB power comes from a regular USB PC port and will not deliver more than 500mA as charging current to the battery. If the USB connector comes from a regular wall adapter, that can provide more than 500mA, then the IC will charge the battery with a specific charging algorithm with maximum 3A. In normal mode, the IC will need only 30mA to work properly and send the required information's about battery status to the microcontroller.
- ***GPIO interface***. This interface will provide user information of the device regarding charging status or the possibility to power up or reset the system. This interface will be user friendly and the displayed

information's will be clear for all type of users. For programming and debug of the microcontroller, the system will have a JTAG programming connector that will be used only one time. The system time will be held using a RTC coin cell battery.

For a complete ECG examination using the proposed system, will be needed a total time of 5 min. (the minimum required time for a correct ECG diagram). If one acquisition of an ECG signal needs 10 sec, in 5 min. will be 30 samples of the ECG signal. In this time, only the microcontroller, the ECG IC, the microSD card and the accelerometer are used. In case if the Bluetooth is used for transmitting the collected data, the total current needed for 5 min. of functionality will be approx. 12mA and 16mA respectively if is used the GPRS module. For a regular use (at least 1 use/day), the system can work for more than 2 month without recharge the battery.

B. *Testing of the m-GreenCARDIO device*

The project was initially prototyped with the MCBSTM32 development kit, that uses the same STM32F107 microcontroller mentioned above, using the MDK 5.21A with the library containing the real-time executive RTX. The Keil RTX is a royalty-free real time operating system based on CMSIS-RTOS API, designed for microcontroller applications. The RTX kernel, along with source files and libraries, is included in the CMSIS-PACK package for Keil MDK [21]. The ADAS1000 chip collects the analogical signals and transforms them in digital data. These information will be sent further to the ST microcontroller via the SPI communication (Fig. 5). In this context, based on the ECG module and the microcontroller produced by ST, the present project aims at improving the quality and the flexibility of wearable cardiac monitoring systems.

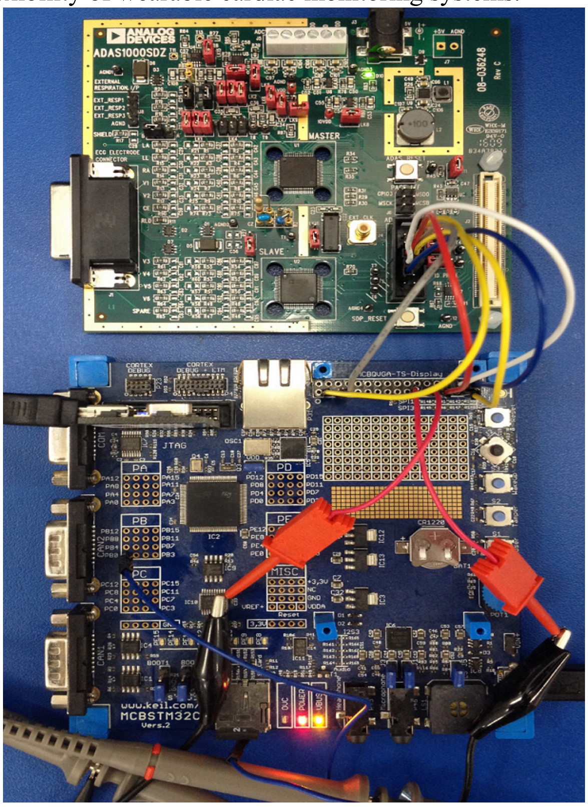

Figure 5. Using the MCBSTM32 and ADAS1000 development kits for performing the trial version of the m-GreenCARDIO project

Almost all embedded systems have no display and keyboard, so that the available inputs and outputs for many microcontrollers can be represented by I/O's, USB, SPI, UARTs, I2C, Ethernet, and CAN. On ARM microcontrollers, the interfaces are controlled by peripherals handled internally by memory-mapped registers [22]. The disadvantage of SPI communication is the fact that it does not support multiple masters, and that slaves cannot initiate the communication and modify data transfer speed [23]. The master can change the clock speed configuration by modifying the clock prescaller register. In order to check the SPI communication with the ADAS1000 chip, each microcontroller pin port was monitored through the PicoScope 2205MSO oscilloscope. The microcontroller is relieved of tasks such as QRS detection, HR calculation, thus using the resources available for the communication with ECG chip, the storing of data in a local memory and managing various communication interfaces, including the healthcare IoT space. The ST microcontroller is the core element of this project, running the RTX real-time operating system. The implementation of a preemptive scheduling of tasks meets the requirements and demands imposed to the system, so that it is imperative that the data acquisition system is one of priority, not to be interrupted by the algorithm tasks or by the user interface (HMI). The local memory is used as a buffer between the acquisition component and the one for data transmission. The large number of input/output ports facilitates the easy implementation of HMI module.

A real time solution for this project could be the nMPRA processor architecture (Multi Pipeline Register Architecture) [24]. Using this processor would add extra performance to the system because, besides the stimulus response speed, it also ensures a low power consumption. The nMPRA processor with functions implemented in hardware can guarantee superior energy efficiency and due to the fact that the actual execution time is shorter.

V. SOFTWARE ARCHITECTURE AND THREAD ORGANIZATION

This paper presents a complete mobile system, which will be implemented and tested as a finished product for monitoring cardiac patients. m-GreenCARDIO device uses a competitive microcontroller and implements multiple communication techniques and interfaces in order to meet the requirements of the application, including an IoT framework for meeting the engineering aim to make technology understandable and accessible for everyone [25].

The threads of the applications are the following (Fig. 6):

- *mgcThreadHMI* ***(HMI)*** – it will ensure the interface with the human operator. For simplicity, m-GreenCARDIO will have one button and three LEDs, so that an inexperienced operator can perform an ECG and transmit the data where desired.
- *mgcThreadECG* ***(Ecg)*** – as the ECG chip, it will manage the operation of the ADAS1000 circuit [26]; it will also manage the accelerometer for the correct positioning of the patient when performing an ECG. The main function of the thread is that of acquiring the ECG signal, by collecting 500 samples per second from the three electrodes, for a period of 10 seconds.

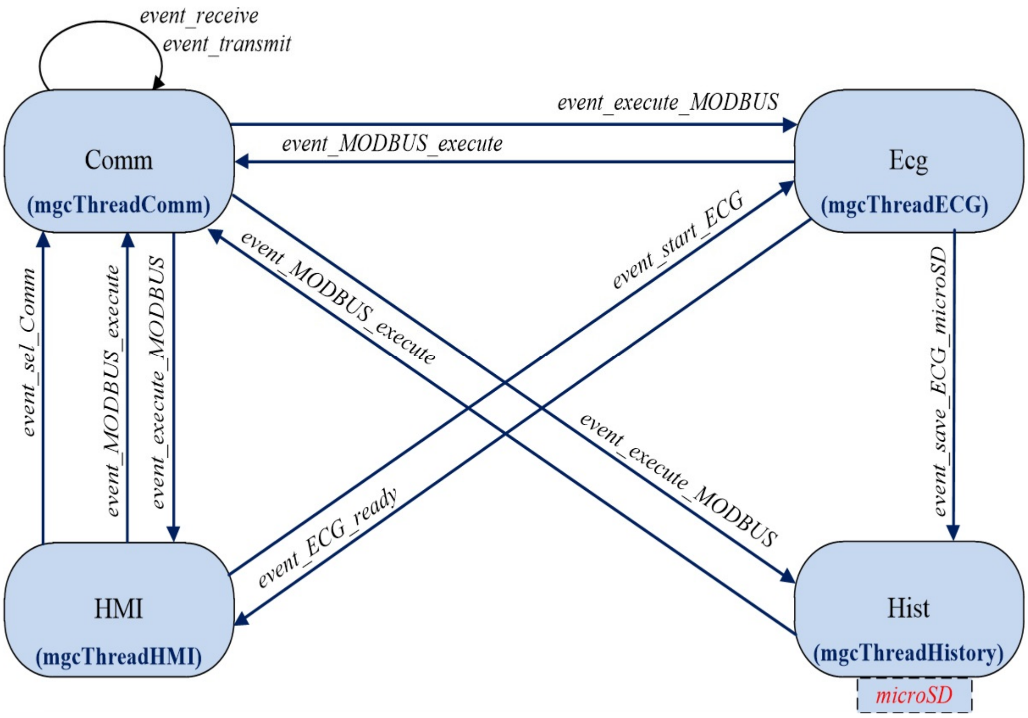

Figure 6. The fundamental machine status for m-GreenCARDIO tasks execution

A sample from an electrode is a 16-bit value in CAN. As a result, the acquisition buffer is of 2 x 3 x 500 x 10 = 30,000 bytes. Also, in conjunction with the communication thread, it enables access to all ADAS1000 registers (calibration operations, accuracy testing etc.).

- *mgcThreadHistory (**Hist**)* – 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 (even if there is one, the ECG is still saved on the microSD).
- *mgcThreadComm (**Comm**)* – performs the communication between m-GreenCARDIO and a PC, smartphone or tablet, in order to transmit the acquired ECG data, or to perform calibration, maintenance and service operations. The protocol used is Modbus, because of its simplicity (only functions 3, 16, and 23) and the possibilities of using the VirtualComm solution on USB and Bluetooth. For GPRS communication, a simulation wrapper for VirtualComm will be written. It will enable the uniform treatment based on the Modbus protocol.
- *mgcThreadSuperVisor* – it performs supervision activities regarding the correct functioning of the device (error reporting, data management, detection of possible blockings, battery voltage etc.).

Based on the above (see also the architecture from Fig. 3) and starting from the fact that the MDK 5.21a and CMSIS development environments will be used for implementation, the software architecture for m-GreenCARDIO will use the *CMSIS-RTOS v1* and *CMSIS-Driver* real-time operating systems. This thread organizing solution was design to simplify and organize the software application. For the same purpose, only the events and the time functions (osDelay) from *CMSIS-RTOS v1* have been used, as well as the drivers for SPI and UART from *CMSIS-Driver* with interruptible property and using callback functions signaling the completion of read/write operations. These signals, corresponding to the SPI communication interface, have been analyzed and monitored through the PicoScope 2205MSO oscilloscope. Regarding the Modbus protocol, space registers have been allocated for the first four threads. For the fourth thread, some special register addresses enable direct operations on ADAS registers, allowing their remote reading and writing (uniformly, for any type of communication, USB, Bluetooth, GPRS - SMS, GPRS Data).

The *mgcThreadECG* thread deals with the acquisition process, having as a main role the acquiring of corresponding ECG data. The software is written in C programming language.

The events depicted in Fig. 6 are briefly explained in the following:

- *event_sel_Comm*: this event is sent by ***HMI*** to the ***Comm*** thread, allowing selection of a communication mode (USB, Bluetooth or GPRS);
- *event_receive* and *event_transmit* are events generated by the callback functions at the full transmission and reception of a complete message (specific to the selected protocol);
- pair type events *event_execute_MODBUS* and *event_MODBUS_execute* launches the execution of a Modbus command to the destination task, and respectively an answer to signal the completion of this execution (from ***Comm*** to the ***Ecg***, ***HMI***, and ***Hist***);
- *event_start_ECG* is an event which lead ***Ecg*** task to launch the acquisition process, and *event_ECG_ready* is an event through that ***HMI*** task is informed by the completion of this acquisition;
- *event_save_ECG_microSD* lead ***Hist*** task to create a file with the latest ECG acquisition on the local memory microSD.

VI. Conclusion and Future Work

This project represents a qualitative research in the field, as it can clearly describe the advantages brought by the efficiency and reliability of the healthcare IoT solutions. As it can be seen, the applications in the field of IoT are constantly evolving. Consequently, it is mandatory that the finished product written and implemented in C source code is flexible, well documented, reconfigured and parameterized.

The design and practical implementation of the prototype is based on a microcontroller produced by ST, the circuit for collecting the ECG signal and modules corresponding to the implemented communications. All these modules form an embedded system. The design and implementation of PCB for m-GreenCARDIO that is part of the medical equipment segment, is a challenge in the field. A variety of shielding solutions are used in the electronic applications. The challenge of this research project is achieved through compliance with the strict rules imposed in the segment of medical devices, which is not always easy to achieve because a lot of knowledge and practical experience are required.

However, the m-GreenCARDIO project is subject to improvements, such as the reduction of the energy consumption, the improving of real-time system performances and the study of the mass production possibility. We have to mention that the current objectives are a follow-up and not an overlay of existing research.

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