A WIRELESS DEVICE TO MODULAR ROBOTIZED INSTRUMENT FOR HEALTH INFORMATION

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ABSTRACT

This article is referred to an innovative wireless device for ECG patient monitoring during minimally invasive surgery. Our aim is to create new type of laparoscopy instruments to improve healthcare. The work presents a wireless device for ECG (DECG) as part of a robotic modular laparoscopic instrument (RMLI). Thus, the device allows ECG analysis and monitoring of the patient to be carried out complexly in combination with other diagnostic and therapeutic (RMLI) mode of operation activities. The proposed device provides detection and rapid warning of abnormal heart rate during surgery. Innovative uMAC wireless network stack is designed for module-control block communication. Control computer program processes and monitors (remotely or directly) received information from wireless device that is connected to patient. The software of the device is developed in Tcl/Tk scripting language for operation under Windows. A shared reality upgrade for Android has also been developed for it. The novelty of the solution is related to the construction and connection of the ECG with the used RMLI robotic module. In the future the designed instrument will can work autonomous. The team has worked in the field of minimally invasive and laparoscopic surgery roboticized instrumentation and the presented development is a continuation of this work.

KEYWORDS

DECG, EKG, wireless device, surgical robotics, health information, Tcl/Tk

1. INTRODUCTION

In recent years, developments and advances in information and communication technologies (ICT) and the miniaturization of diagnostic devices have increasingly become part of our daily lives. In this way, thanks to the improvements provided by ICT, people have an intelligent lifestyle with more opportunities and free time. These improvements are felt most strongly in the areas of healthcare [1, 2] safety and reliability [3], automation of household appliances and smart services. New technologies are present in the entire cycle of patient treatment, they are also observed in operating rooms like robotic systems for minimally invasive surgery [4, 5] Modelling system tools and sensor networks [6, 7], as well as collection systems, are increasingly being used of information and its subsequent processing in the field of medicine and surgery. Some of them have applied unified modelling languages - UML [8, 9]. Some wireless networks for medical applications [10, 11] [4] have been developed thanks to elements and devices in the electronic and information progress [4].. Nowadays, in results of the technological advancement

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the world is moving towards miniaturization of devices in various fields. This also includes a medical field where the doctor can effectively analyse various diseases and continuously monitor various vital signs of the patient during an operation, including laparoscopic operations, which have recently replaced conventional surgery. ECG monitoring during bloodless surgery is mandatory throughout the operation. The electrocardiogram (ECG) results are indicative for the human heart conditions. Advantage of ECG monitoring devices is result from compactness and portability of the developed wireless heart rate monitoring devices [12, 13]. The development of new EKG devices is related to some challenges such as precision, convenience and low cost [13, 14]. hardware and software implementation, communication, wireless transmission, signal processing and analysis [15, 16, 17]. New types of devices for measuring ECG, heart rate, oxygen values and their application pose new challenges in the processing and analysis of measurement results and increase the need for automatic, inexpensive, real-time and effective monitoring of these parameters that can be used at home and/or in outpatient. Many problems about minimally invasive surgery are solved through robots in the operating rooms. The novel robotic systems are designed modularly and, in addition to the main laparoscopic instruments, additional diagnostic modules are also developed to monitor vital functions of the patient and the necessary equipment during the manipulations. The actuality of the problems can be seen from what has been listed so far.

This paper proposes an innovative wireless device for ECG patient monitoring during minimally invasive surgery. It aims to introduce a new type of laparoscopy instrument to improve healthcare. A robotic modular laparoscopic instrument is developed and manufactured, discussed in detail in previous studies [18]. The instrument is intended for diagnostic and therapeutic procedures in laparoscopic surgery. RMLI is built on a modular basis, comprising a common base platform and a set of integrated intelligent modules. The instruments for monitoring the patient's current condition have also been designed for the needs of RMLI. An operator's panel, a specialized management controller and different sensors to monitor various vital signs of the patient during the operation are situated there. Together with the Specialized Controller, they form a wireless radio network and exchange operational information with each other in real time.

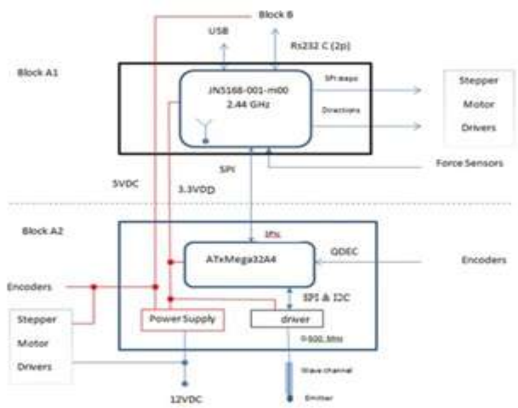
The paper examines the designs of a wireless ECG (DECG) device as part of a robotic modular laparoscopic instrument (RMLI), dedicated controller and its capabilities for working with the designed diagnostic wireless ECG device (DECG), detailing the design of the DECG and its connection to the Dedicated Controller. It, together with the Specialized Controller (managing the RMLI) form a business radio network and exchange operational information with each other in real time. The wireless device is an important part for monitoring the patient's current condition during medical procedures. The possibilities for designing other modules to the robotic system are also presented. In conclusion, the prospects for refitting the RMLI and the possibilities for other DECG applications are indicated. The proposed device allows ECG analysis and patient monitoring to be carried out complexly in combination with other diagnostic and therapeutic (RMLI) modes of operation activities.

The article includes several sections: Introduction, Architecture and functions of a dedicated controller to control RMLI AND DECG; Device and Mode of Operation of a Wireless Diagnostic Tool (DECG) and Conclusion indicating future directions for work on the subject.

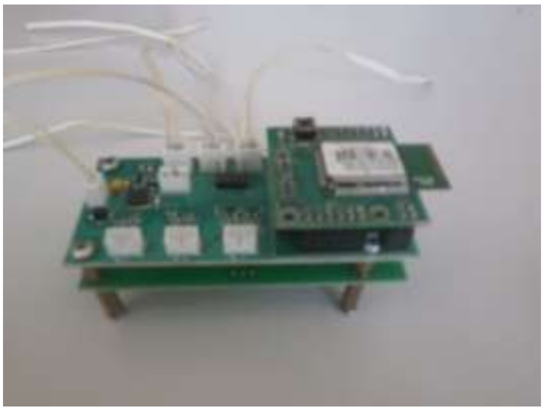
2. ARCHITECTURE AND FUNCTIONS OF A SPECIALIZED CONTROLLER FOR MANAGEMENT OF RMLI AND DECG

During surgical procedures, there are devices used for monitoring of various vital signs of the patient. The robotic modular laparoscopic instrument for minimal invasive surgery - RMLI was developed and designed. It performs diagnostic and therapeutic procedures in laparoscopy [18, 19]. An operator's panel, a specialized controller, electromechanical linear drives and tactile force sensors tor tool-tissues interactions as well as the additionally included modules for monitoring ECG, pulse, etc. [18] are situated in the platform. This article describes the operation of the Dedicated Controller and its connection to the Wireless ECG Monitoring M. The Specialized Controller [18] designed for: control of mechanical movements realized in RMLI and providing graphical interface (GUI). In such way surgeon can set commands to the RMLI, monitor their execution, receive a visual operation of the patient's condition, connect via wireless Internet to a remote server or client, in order to receive additional auxiliary information formed in energy-independent memory about the actions performed with RMLI and the indicators of the operated chronologically during the operation process [20];

- Maintaining a wireless connection with intelligent devices participating in and ensuring the successful progress of the laparoscopic operation (ECG mobile devices, wireless sensors, etc.);
- formation of text and sound messages upon detection of inadmissible deviations in the operation of the RMLI (or the module installed to it), unacceptable changes in the indicators of the operated or incorrect commands given by the operator. The dedicated controller is built on the basis of two functional blocks A and B. Block A consists of two sub-blocks (A1 and A2). The communication of A1 and A2 is realized via an SPI wire interface. The dedicated controller is shown in Figure 1 (a, b).



a) Block diagram of block A



b) Controller

Figure 1 a, b. dedicated controller

Block A performs is a master device and is responsible for (fig. 1 a):
A two-processor device based on specialized wireless microcontrollers JN5168-001-M00 of the company NXP [21] and industrial microcontroller ATxMega32A4 of ATMEL [22] are situated in a Block A.

Block A2 includes an ATxMega32A4 microcontroller [22], for processing the signals from the encoders to the stepper motors using built-in QDEC automata. It uses the built-in independent SPIs (I2Cc together with SPId) to communicate with the JN5168-001-m00 (block A1) and control a dedicated driver forming a programmable radiotherapy frequency signal. A built-in block for generating all the voltages necessary for the operation of the devices included in the RMLI is located in A1. Block A1 is controlled by its on-board JN5168-001-000 [19] as the on-board SPI forms pulses to generate motion for stepper motors, receives and processes signals from force sensors using its analogue inputs ADC0, ADC1 and ADC4,.It has a built-in radio antenna, generates and supports work with a wireless network and with external network devices. A1 supports a connection from block A to block B, via a serial RS232 C interface with its own built-in USB as a service interface or for loading a special management program into the flash memory

JN5168-001-M00 (A1) has two serial ports (UART) - (UART0) is used to service and load the program in CPU flash, (UART1) to communicate with block B. The microcontroller functions as the main device in block A. The JN5168-001-M00 is a network wireless device and is managed using the dedicated uMAC stack [23] functions as a Gateway of a wireless network including intelligent devices participating in and ensuring the successful course of laparoscopic surgery (ECG mobile devices, wireless sensors, etc.).

On the figure 2 is shown Graphical user interface of a Local Operator Station.

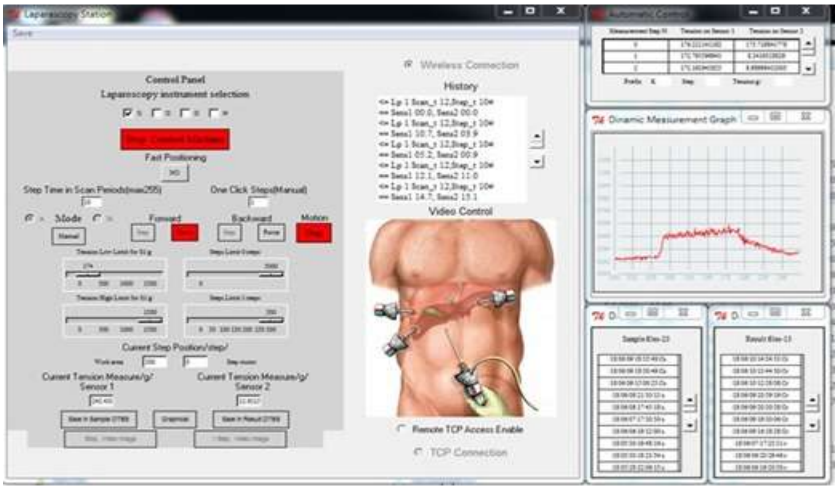


Figure 2. Graphical user interface of a Local Operator Station

The software of the station is developed in Tcl/Tk scripting language for operation under Windows. A shared reality upgrade for Android has also been developed for it. Detailed in [19, 20]. The operator station is intended for work on a personal computer, tablet or laptop. It functions as a Wireless Local Area Network (WLAN) coordinator and implements a Graphical Programming Interface for the Surgeon-Operator. In addition to the configuration of the robotic laparoscopic instruments involved in the operation, their programming, the visualization of the work of their end-effectors, it functions as an advisor to the Operator. For this purpose, it includes. Database with a library for generating different types of movements, for the different instruments; a program mechanism for recording all the actions of the tools with the possibility of reversing each of them; Information system about the patient's condition, including the history of his illness, current values of vital signs (ECG, pulse, etc.), the medical file, information about cardiac activity during the operation

Block B device and its functions

Block B implements the RMLI operator interface. It is designed based on gen4-IoD-28T (2.8" TFT LCD module with Resistive Touch) of 4DSYSTEMS Company. More detailed information can be found in 4DSystems, [24]. The device provides the operator with a full-fledged 2.8" intelligent LCD-TFT display driven by ESP8266 GPU [25].

Figure 3. Device gen4-IoD-28T [24].

It is convenient to use with other devices. It has a 2.8" color TFT LCD display with a resistive touch screen. Supports Wi-Fi set of functions for the user. The Gen4-IoD-28T is easily programmed with the 4D Systems Workshop4 package [26]. allows use of easy graphics functions, SD functions, touch control functions, all integrated in one library. SD The design of the user screen is done OFF LINE, by creating a project in the WORKSHOP4 program package of the 4DSystems company, which works under Windows and includes a designer, editor and compiler. A specialized C-like language was developed to design the various applications. It allows the design of the graphical user interface, associates actions related to the created touch buttons. After generating user executable code for an application, it is loaded via USB into the processor's FLASH memory or an application library on the SD card. Only one application can be launched, but during its execution it can load another one from the SD library and activate it. The SD card can record and store operator data and actions. Block B communicates with Block A over a serial interface connecting its ZIF socket built-in user UART to Block A's JN5168-001-M00 UART0 using a dedicated communication protocol.

A Recon Jet™ Pro AR Dedicated Display [27] with virtual reality elements is possible to block B. It is designed as smart glasses, in which an auxiliary display is installed, on which important data about the patient's condition is projected, in addition to monitoring. Display data is sent via Wi-Fi from unit B so the surgeon does not have to monitor the touch screen on unit B. The dedicated display is autonomously powered and can be turned on or off as desired. Figure 4 shows the appearance of the dedicated display.

Figure 4. ReconJet™ Pro AR Dedicated Display [27].

3. ARCHITECTURE AND FUNCTIONS OF A SPECIALIZED CONTROLLER FOR MANAGEMENT OF RMLI AND DECG

A sensor module is fundamental in the structure of RMLI, made up of a communication wireless micro-controller (which automatically makes it a network device) and built-in sensors for measuring quantities related to the operation process of the laparoscopic instruments - pressure, the level of CO2 in the abdominal cavity of the patient, temperature, humidity, ECG and other indicators and parameters. In this way, the information received from these sensors can be made available to the laparoscopic instruments of a given group and or the Operator Station using the built wireless network of the group. The main element is the diagnostic device DECG, designed to control important vital parameters during the operation. It is implemented as a wireless network device that monitor the state of the operated patient in real time. This is done by cyclically generating an ECG in digital form and sending it wirelessly to the Controller block A of the laparoscopic instrument. In this block, an analysis of the received digital for parameters such as pulse, heart activity, blood pressure, body temperature, etc. are carried out.

These parameters are measured in an area where the probe of the device is fixed. Several such devices with different placement of the probes connected to the patient's body can be installed. Thus, it becomes possible for the laparoscopic instrument to obtain a complex picture of his condition. These measurements may be later used as primary data for further complex tasks such as deep learning algorithms [28] or finite element calculations in various cases [29]. The measured and specified data serve as feedback in the programs controlling the instrument, and can also initiate an audible alarm message in the presence of dangerous deviations. These data are present on the touch screen of the Controller block B (in graphic and digital form) and informs the surgeon about the current state of the patient.

In the current project, this module is implemented as a mobile ECG. It measures the electrical potential between two points on the human body, forms an ECG-gram and sends it on request over the wireless network to the JN5168-001-M00.

A standard ECG uses electrodes connected to important points on the patient's body: 1. Right arm, RA; 2. Left arm, LA; 3. Left leg, LL; 4. Right Leg, RL; 5. Chest, C.

Depending on the connection of the electrodes to the ECG sensor, different forms of the signals and their amplitudes can be observed. Each pair of electrodes provides unique information about the heart's activity.

The device consists of two modules:

- Controller developed on the basis of JN5168-001-M00 [21];
- Measurement developed on the basis of MAX30003 [30].

Figure 5 presents a schematic diagram of the developed controller.

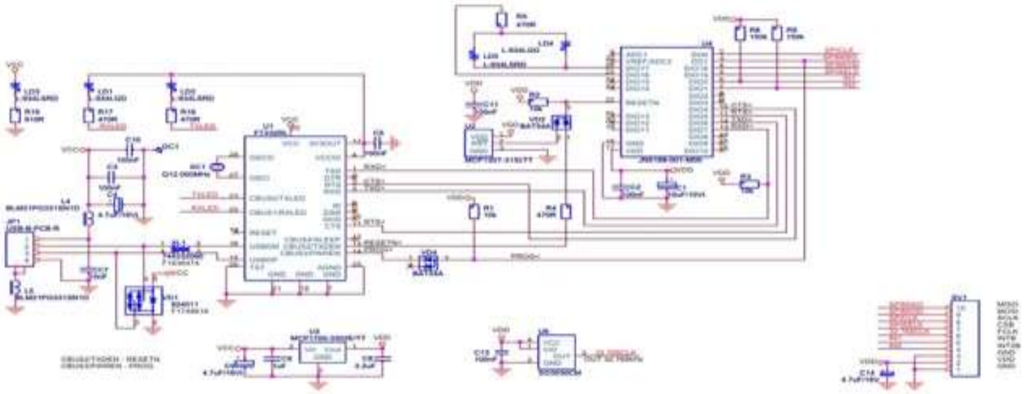


Figure 5. Schematic diagram of the control module based on the JN5168-001-M00

Schematic diagram of the measuring module shown in Figure 6.

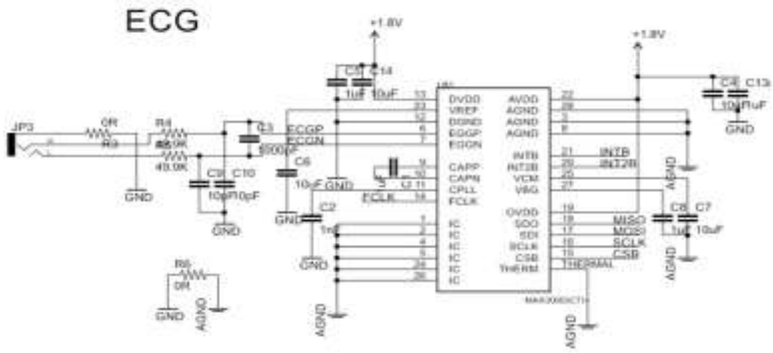


Figure 6. Schematic diagram of the measuring module

The power supply is provided by the control module based on 5VDC received via USB cable from USB interface or from 220V AC to USB converter.

The measuring module connects to the controller via SV1 (Figure 5)
The power supply of the instrument is provided by the control module based on 5V DC received via USB cable from USB interface or from 220V AC to USB converter.

The control module controls the operation of the meter. It also ensures the communication of the instrument via a wireless interface - uMAC [23] or wired - USB. The measurement module generates the patient's ECG via two serviceable electrodes and sends the information via an internal SPI interface to the controller.

Electrodes can be connected bipolar, unipolar and unipolar to the chest. Bipolar connected, depending on the choice of contact points, can be divided into 3 groups: Lead I, Lead II or Lead III, shown in figures 7 and 8.

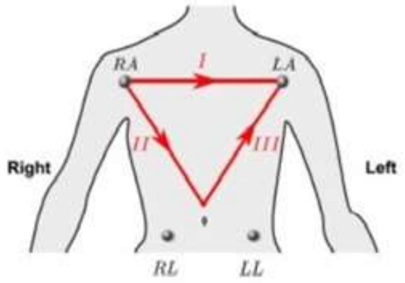


Figure 7. Standard limb led positions, bipolar. Einthoven. Einthoven triangle [31].

Figure 8. Signals from standard ECG [32].

Figure 9 shows different types of electrodes that are used in ECG devices.

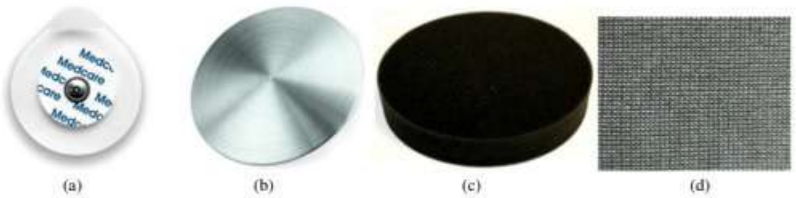


Figure 9. Electrodes categories: (a)conventional Ag/AgCl, stainless-steel disc, (c) conductive foam and (d) conductive fabric [33].

More information on electrodes can be found in [14, 15].
A specialized integrated circuit MAX30003 [30] was used for the implementation of the diagnostic ECG device, performing all analog processing of the signals from the electrodes and supporting an SPI interface with a wireless microcontroller JN5168-001-M00.

The device (DECG) includes: two ECG electrodes, integrated circuit MAX30003 (implementing Ultra-Low-Power, Single-Channel Integrated Biopotential (ECG, R-to-R, and Pace Detection) and Bioimpedance (BioZ) AFE) two-electrode device SPI connected to JN5168-001-M00. The latter functions as a wireless network device, buffering the received digital information, and sending it over the wireless network to block A (JN5168-001-M00 of this RMLI block), when requested by the latter. The uMAC wireless network stack used to connect to the dedicated controller is described in detail in [23]. Figure 10 shows the topological diagram of an uMAC network designed to control laparoscopic instruments.

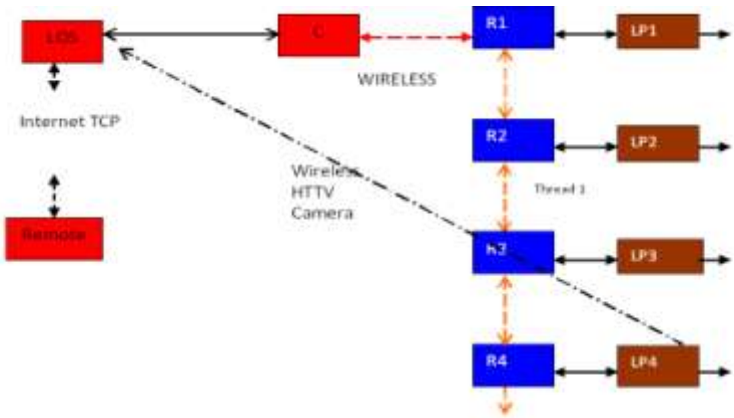


Figure 10. uMac Laparoscopy WLAN

As shown in Figure 10, only one thread, Thread 1, is used in this case (the standard uMAC supports tree topology networks including up to 4080 threads, each of which implements an autonomous subnet with unlimited length and a limited number of the nodes included in it up to 2805 [23]). The wireless network microcontrollers (R1, R2, R3, R4) controlling individual tools to the robot (LP1, LR2, LP3, LP4) are four and are included in Thread 1, as Wireless Local Area Network (WLAN) Routers. Each of them contains in its memory an IEEE 802.15.4 stack, a uMac stack, and a user program corresponding to the type of instrument it controls. The network coordinator is denoted by ”C”. It is connected via a wired USB channel to a Personal Computer in which the Local Operator Station resides. The coordinator creates the network, maintains communication with the routers, and provides relaying of entries between routers and a local management program. The IEEE 802.15.4 stack, the uMac stack and a user program responsible for maintaining a communication protocol with the Local Control Program are loaded and running in its memory.

The uMac stack is designed to work with means of controlling mechatronic objects, designed on the basis of wireless microcontrollers JN5168 of the company NXP. The control system is implemented as a wireless network, including two types of communication devices - "Gateway" and "Controller". These devices function as coordinators of wireless networks (IEEE 802.15.4) that do not include other nodes (empty LAN). The “Gateway” is designed based on the JN5168-001-M00, functioning as a communicator and adapter, converting a serial channel (3.3V) to USB, bi-directionally. "Controller" is designed based on JN5168 -001-M00 and a peripheral module connected to it, controlling the sensors and actuators connected to the managed object. An Operator Station has been developed to work under Windows (for a personal computer, laptop or tablet), with possibilities for programming the tasks and monitoring the states of the managed objects. Two logical channels are used to work with the Gateway - through the graphical interface of the Operator Station or directly, via USB in InLine mode, through a special command language. Block: Remote (figure 10) is intended for connection with remote wireless devices of the type of the considered DECG diagnostic tool.

The block diagram of the Diagnostic Tool (DECG) is shown in Figure 11.

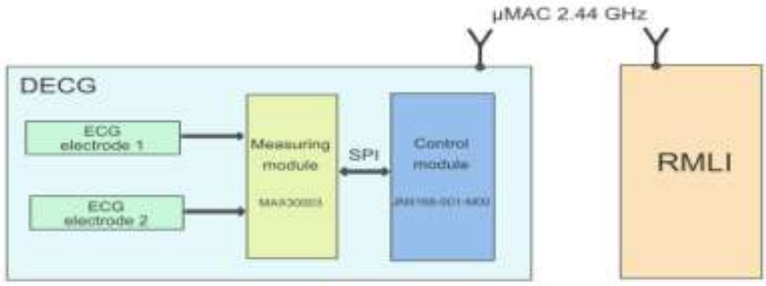


Figure 11. Diagnostic Tool Block Diagram (DECG)

The Diagnostic Tool (DECG) feeds the measured information via the µMAC protocol to Block A of the Dedicated Controller, which via RS 232 C protocol feeds the gen4-IoD-28T information (Block of the RMLI Dedicated Controller). Detailed information on the operation of the gen4-IoD-28T is given in the description of Block B. The measured information is accumulated in a local database on a SD card and is submitted to the RMLI Operator's Station upon request.

The operator station is connected to the Internet and could provide authorized online access to external information sources and specialized databases. In the future, the possibility to save the complete information about the patient's condition on a personal smart card will be considered. This information could be used by the personal physician or other doctors monitoring the patient.

4. CONCLUSIONS

An intelligent operator panel has been developed, based on the use of a graphic touch screen, for convenience of usage. The screen is used both for management and for information visualization during the operating process. Additionally, for receiving and visualizing important messages specialized glasses, using the method of virtual reality, has been implemented. Specialized software has been developed for management of the various devices included in the RMLI, as well as the realization of real-time diagnostic and test procedures of their functioning. The software of the wireless device is developed in Tcl/Tk scripting language for operation under Windows. Development of more autonomous devices is planned for diagnostics and other vital indicators such as pulse, blood pressure, etc. to work together with the developed RMLI system.

The future work will consider development of a device incorporated into the RMLI that will monitor and regulate the level of CO2 in the patient's abdominal cavity during operations.
The developed module DECG is able to function as a autonomous unit, independently from the RMLI Operator's Station.

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