physiological recorder, environmental recorder, flight parameters, ECG, NIBP, EMG, SpO_2, GPS, GPRS, WiFi

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COMPREHENSIVE METHOD OF RECORDING PSYCHO-PHYSIOLOGICAL AND ENVIRONMENTAL SIGNALS DURING FLIGHT

In 2011 ITAM has completed work conducted with WIML's representatives to develop a comprehensive method of psycho-physiological pilots' signals and external environmental parameters during a test flight. It has been assumed that data will be collected "off line" during a training flight and stored in the monitoring module's memory, and after the flight it will be loaded to the operator's station system at the airport. The "On line" transmission of chosen parameters directly into a database and ongoing observation have also been anticipated. One of the main assumptions for the system was its independent work from the avionics systems of aircraft used for training. This has made it possible to use the system regardless the type of aircraft equipment and without having the necessity to stringent criteria of aviation hardware acceptance.

The recording system has been designed as a distributed system consists of modules carried by the pilot, those placed permanently in the cockpit of the plane, a station for test flight preparation and reading recorded data, as well as a database system accessible via the Internet. Communication between the various system modules is to employ various transmission systems, wired as well as wireless. For safety reasons wireless communication between modules in the cockpit was not used in flight, with the exception of GSM transmission used to transfer selected data directly to the Central Acquisition System.

1. INTRODUCTION

Studies of changes in biological parameters of pilots during training were conducted in WIML using appropriate aviation training equipment on the ground. They did not fully reflected conditions that occurred during real flight training. The obvious solution seemed to be the transfer of monitoring the chosen physiological parameters essential for assessment of a pilot's health to the cockpit and recording the data during a training flight. Such solutions have been developed with the involvement of ITAM in the VENTUS recorder, which allowed to record only a few physiological (ECG, temperature) and environmental (g-force and atmospheric pressure) parameters. It was therefore decided to begin the development of a more sophisticated system for parameters recording, one that would work during a training flight.

2. BASIC INFORMATION

The objective for the system implemented for the Polish Air Force Academy in Dęblin was to perform measurements and execute the monitoring of a significantly more numbers of physiological and environmental parameters than in the VENTUS system case. The new system that was to be developed took the name SMP-300 and supposed to be something more than just a recorder of various parameters. Its composition has also included elements allowing to prepare the pilot for monitoring, extensive data acquisition mechanisms operating after the end of the flight and during the flight as well as a database system. This subsystem was to collect results of studies conducted during training flights, make them available via the Internet and provide mechanisms for authenticating access to such data. Elements of the system placed on board of the aircraft should have been work independently to the airplane avionics systems, so that they could be used in different types of craft and cause minimum interference with the airframe structure, and produce an acceptable level of interference which could affect the aircraft's systems. Figure 1 shows the architecture of the developed SMP-300 recording system.

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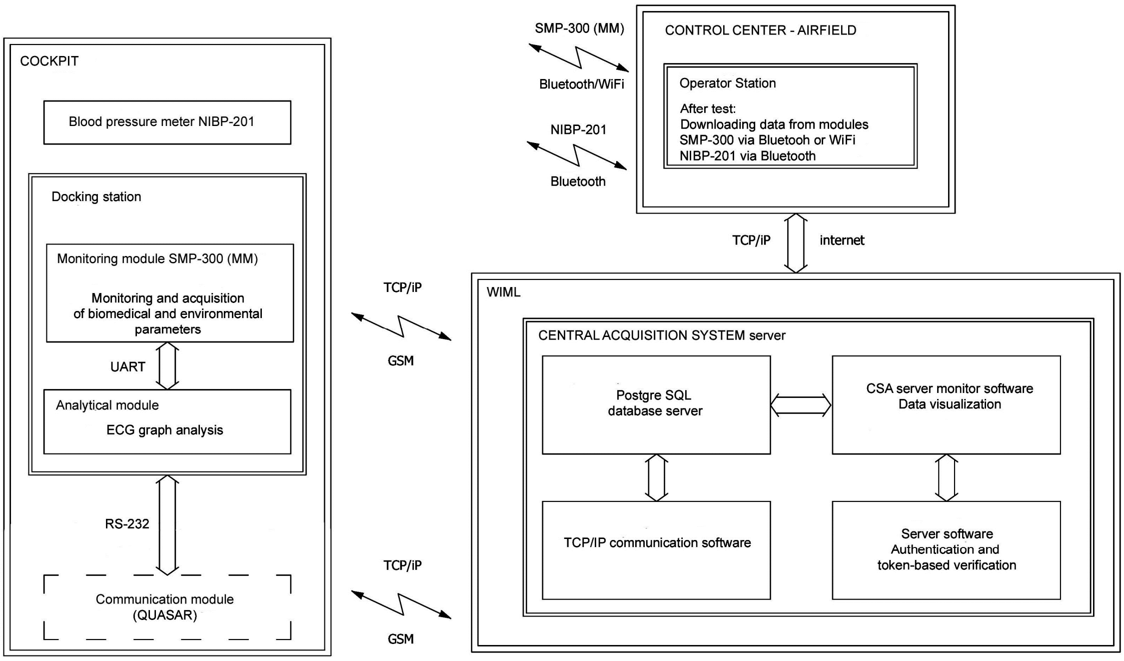

Fig. 1. Block diagram of SMP-300 system configuration.

As it has been illustrated, the system works in three different locations. The first of them is the aircraft cockpit, where monitoring of biomedical parameters and recording environmental parameters for reconstruction of flight parameters are performed. The main module responsible for monitoring parameters is the SMP-300 Monitoring Module, connected by wires with sensors placed on the person being monitored (e.g. a pilot) and powered by batteries. This is a portable module and, although during the flight it is placed in the Docking Station installed in the cockpit, but after the flight it is removed and transferred nearby the Operator Station at the airport. The procedure is similar for the NIBP-201 pressure measurement module attached to the pilot or another monitored person on board of the airplane. Placing the SMP-300 module in the docking station is necessary, because during the flight it transfers data via a serial link to the analytical module also placed in the docking station. The analytical module processes received data and can transmit the results back to the SMP-300 module for recording or transmission by a GSM mobile link or for transmission using another communication module (optional module from QUASAR used). Data is recorded mainly in the "off line" mode, in the memory of the SMP-300 module, but some selected data and results of its processing are, if it is possible, sent in the "on line" mode through a mobile data network.

The second characteristic location of part of the system is the Control Center at the airport which operates training flights and where the Operator Station is located. The Operator Station software allows to prepare the monitored person (pilot or passenger) for data recording. Once the sensors and the pressure cuff are connected, the correctness of the recording can be verified on the Station monitor and parameters are possible to determined. When the preparations of the monitored person are over, the person goes to the plane, places the SMP-300 module in the Docking Station and performs a training flight. When the flight is finished, entity returns to the Operator Station surroundings, in which recorded data is transmitted to the Station. Communication between the Monitoring Module and the Operator Station is done via WiFi net or Bluetooth, and via Bluetooth between pressure measurement module and the Operator Station.

Data obtained from the modules is transmitted by the Operator Station to the Central Acquisition System installed on a server in the third system location (at WIML). The CAS software handles a database with monitoring results recorded in-flight, records data transmitted through the mobile network during the flight, and makes available and visualizes information stored in the database. Access is given to chosen people authenticated through hardware tokens.

3. SMP-300 MONITORING MODULE AND COCKPIT EQUIPMENT

The SMP-300 Monitoring Module is the main recording parameters module during a flight. It performs recording all of the parameters in the system, with the exception of blood pressure measurements performed by the NIBP-201 module.

The module monitors ECG graphs from two independent leads with a frequency of 1000 samples per second. It has a respiration monitoring system that uses the reografic measurement method with an impedance variability caused by breathing in the range between 0 and 1Ω, sampled at 500 Hz, and monitors the electromyographic signal in two independent channels with a frequency response up to 250 Hz. The SMP-300 module also leads the oxygen saturation SpO_2 measurements and monitors the plethysmography graph using a commercial SpO_2 module, as well as measurements of changes in skin impedance from 10 kΩ to 200 kΩ.

The SMP-300 module also conducts measurements and stores environmental parameters on board of the airplane: ambient temperature, humidity and atmospheric pressure. It is also equipped with modules that allow to determine its location and movement dynamics: a GPS module, module of the acceleration measurements in three orthogonal axes XYZ (accelerometer), as well as a gyroscope and magnetometer. Figure 2 presents the module's structure and shows the location of each measurement subsystem.

Due to the technical difficulties in accessing to parameters recorded by the measuring apparatus of the airplane and independence from the type of machine, it has been decided that the monitoring module will be equipped with an autonomous function for recording the following flight parameters: speed, altitude, tilt, inclination, course, and measurement of astronomical time . Measurements of these parameters are performed with the aid of a built-in GPS module, accelerometer, gyroscope, magnetometer, and atmospheric pressure sensor. In order to ensure appropriate operating conditions for these sensors, it has been decided that the SMP-300 Monitoring Module should be installed in a Docking Station directly to the body of the aircraft.

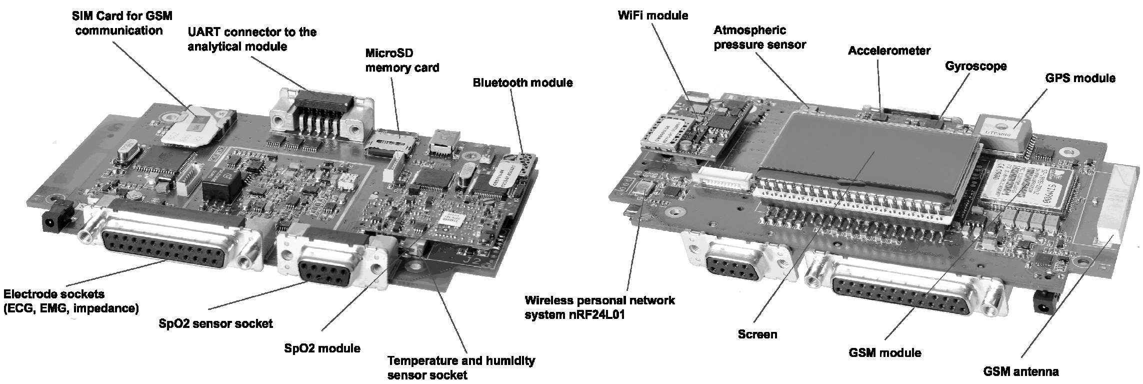

Fig. 2. Structure of the SM-P300 Monitoring Module.

The SMP-300 module is equipped in a number of wireless and wired communication systems. In addition to the aforementioned WiFi and Bluetooth communication modules used to communicate with the Operator Station and the GSM mobile communications module (Figure 2), the module has been equipped in a low power communication system based on Nordic's nRF24L01, designed for personal communication networks, which was not used in the SMP-300 system, and an UART serial connection. For safety reasons, wireless communication systems were not used during the flight of the aircraft and communication with the Analytical Module in the Docking Station was provided through a wired serial interface, after the monitoring module was placed in the Station. Since the Monitoring Module fulfilled the requirements of medical devices standards and the directive, and was directly connected to the monitored person using the application parts of this medical device, the UART interface was galvanically isolated from the Analytical Module for reasons of safety. For the same reason it was powered by an internal battery and charged before monitoring. The Monitoring Module was supported by two microcontroller chips. The AT32UC3B0256 microcontroller chip was responsible for ECG signal monitoring, respiration, EMG, skin impedance, managing Bluetooth and WiFi wireless communication modules, support for the SD memory module and the screen, while the ATXMEGA128 GSM handled GSM communication, Nordic, reading data from the SpO_2 module, and conducted measurements of environmental parameters and the dynamics of module movements.

The Docking Station shown in Figure 3, in which the Monitoring Module was placed during the flight, included a built-in analytical module responsible for performing the required data analysis. The module was used for ECG graph analysis and calculating the following parameters: HR - heart rate, VEB/min - ventricular ectopic beats, VPC/min - ventricular premature contractions, VESC/min - ventricular escape beat, averaged QRS, AR - information about arrhythmia, STu - ST-segment elevation, STN - ST segment slope and HRV (t) - heart rate variability analysis index.

The Analytical Module was based on a commercially available PC module, which software was developed for the use of the SMP-300 system based on analytical software from ITAM.

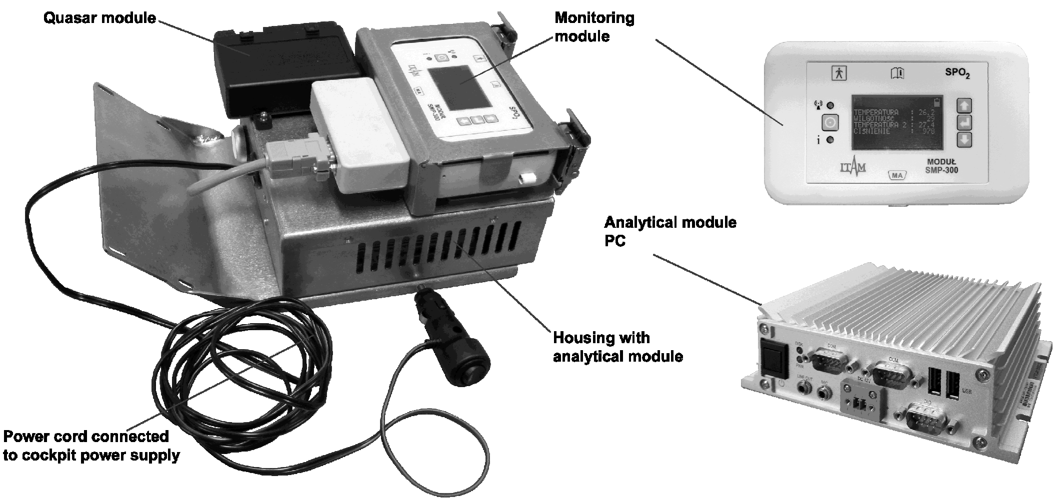

Fig. 3. Docking Station with Analytical Module.

The hardware of the SMP-300 Monitoring Module was sufficient to forgo installing other modules in the cockpit subsystem, as it was capable to put across of GSM mobile transmission and equipped with a GPS satellite navigation module. However, it was ultimately decided to use a different system for this purpose - a module from QUASAR Electronics based on their Q-SAT QRT01 specially adapted for providing satellite navigation and GSM transmission in mobile communication systems. It was equipped with external GPRS and GPS antennas, which improved the range and sensitivity to satellite signals. QUASAR's module was connected to the Analytical Module through a serial RS-232 connection used by the analytical module for transferring information, which was then directly sent by GPRS to the Central Acquisition System.

4. OPERATOR STATION AND CENTRAL DATA ACQUISITION SYSTEM

The Operator Station was built on the basis of a PC computer equipped with a Bluetooth 2.1 communication interface. By definition the station ensured permanent access to the Internet for communication with the Central Acquisition System (CAS). The Operator Station (SO) software was designed for the OpenSUSE system platform using Qt libraries, the GCC compiler and the Bluez library to communicate by Bluetooth interface. The Operator Station application makes it possible to view physiological parameters of the pilot and environmental parameters occurring in his or her surrondings during the test. In addition to the presentation of two lead ECG analysis, an analysis of this signal was used comprising: detection of the QRS complex, determination of the heart rate (HR), detection of ventricular ectopic beats (VEB), determination of the average beat, setting out ST segment parameters (elevation and slope) and the detection of arrhythmia. The whole system allows for easy and clear viewing of the performed test.

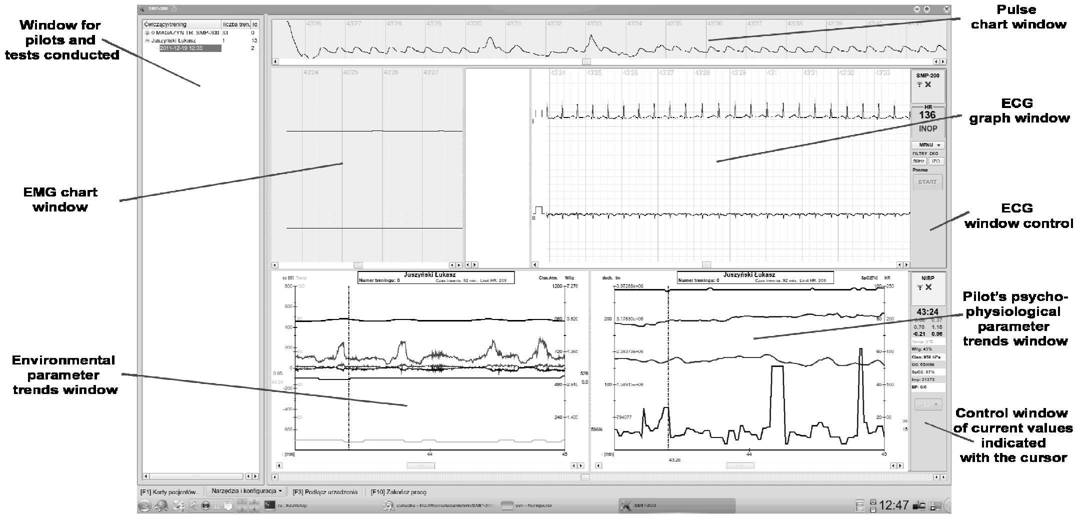

Fig. 4. Presentation of recorded data on the Operator Station screen.

The CAS system has been designed and built using the latest, while at the same dependable, web solutions. The software was developed on the basis of PHP + PostgreSQL in the latest stable versions. Additionally, the jQuery and jQuery.UI library was used along with attractive extras for data presentation (tables, graphs), which resulted in the creation of a flexible and user-friendly tool. The system framework is based upon an object-based application framework that uses an MVC (Model - View - Controller) design template, so that particular application layers (data, users' interface, control) were separated, which make a modular design and future development of the system possible. Access to data is authenticated and transmission is protected through encryption. Just as in the Operator Station application, the Central Acquisition System presents the physiological parameters of the pilot and environmental conditions of the test. In addition to that, the current location of the aircraft is shown on a physical map.

5. PRELIMINARY TEST OF SYSTEM

Prepared, actuated system was tested in the laboratory of ITAM. The test showed that all biomedical parameters were monitored properly and the system in terms of functional behaved as expected. Measurements of environmental and dynamic parameters were also correct, except for the external temperature and humidity measurements. Placing the temperature sensor inside the enclosure has led to an increased temperature measurement in relation to the actual ambient temperature, despite vents being left. After the design change the sensor was placed on the outside of the enclosure. The functioning of the SMP-300 system in movement was checked by performing monitoring while travelling by car, using a portable battery to power the Docking Station. Signal recording as well as GPRS communication with the Central Acquisition System were both performed correctly. The ultimate test of the correctness of system operations was to conduct tests during an actual training flight.

The SMP-300 system supposed to be use during the training flights at the Polish Air Force Academy in Dęblin and adapted for installation in training airplanes purchased by the Academy - Z242L (two-seat plane) and Z 143SLi (four-seat plane) from ZLIN Aircraft. These aircraft were adapted by Zlin in a way that allowed SMP-300 system components to be connected to the aircraft power supply system and the Docking Station to be installed on board of the aircraft.

The test of the SMP-300 system during a training flight was conducted in Dęblin from the Air Force Academy airfield. Flights were done on a two-seat Zlin Z242L airplane. The person monitored during the flight was a passenger connected to the SMP-300 Monitoring Module using applicative cables. All biomedical parameters were monitored except for EMG records. Blood pressure measurements using the NIBP-201 module were not performed either. After correct signal acquisition was confirmed on the ground, the training flight began. The flight demonstrated that GPRS transmission enabled monitoring of the person tested and "on line" flight parameters up to an altitude 400 to 500 meters. Transmission above this altitude underwent suspension and data was not recorded in the Central Acquisition System. Once the flight descended lower, data transmission resumed and the system also transmitted data stored during the break in transmission.

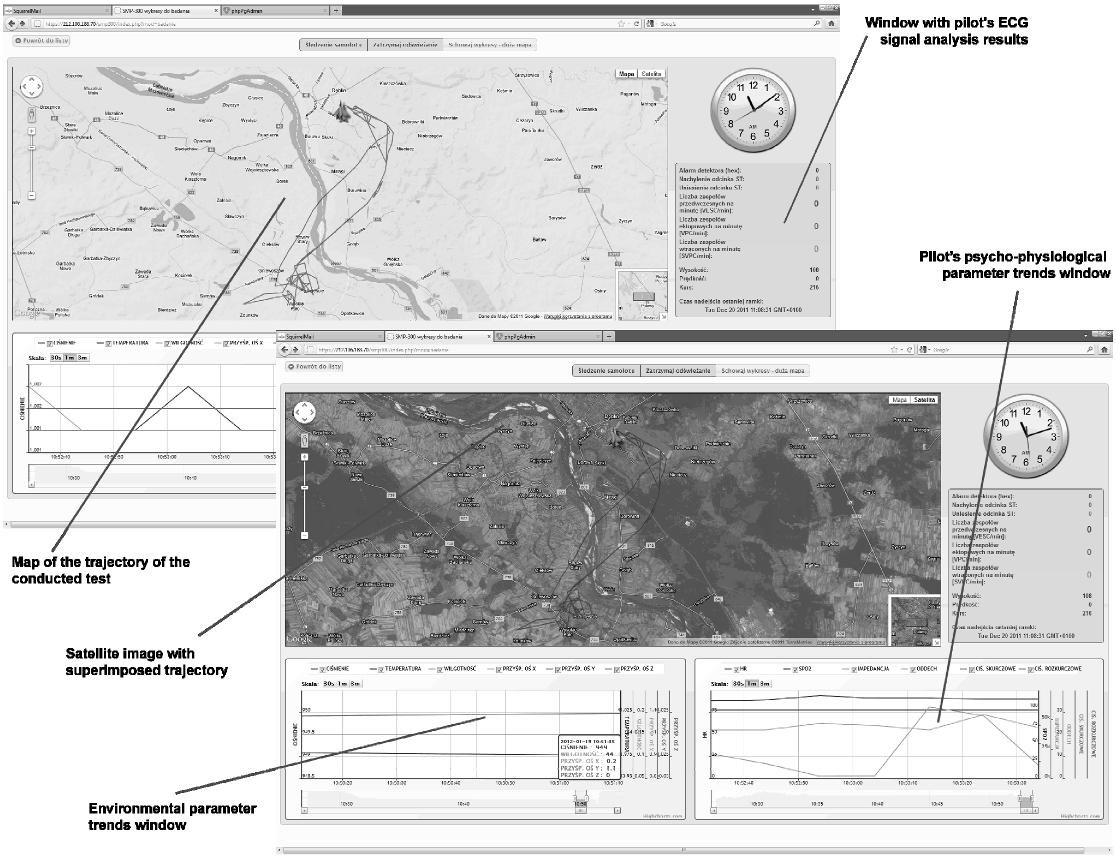

Fig. 5. Presentation of data "on line" upon return from a flight, on a computer screen with access to the Central Acquisition System.

Figure 5 shows snapshots of the Central Acquisition System performed during the aircraft's approach for landing. They also show the flight trajectory on a map or in a satellite view, as well as change trends in biomedical and environmental parameters just before the flight finished. The screen also shows ongoing statistics for parameters and ECG abnormalities recorded by the Analytical Module, as well as ongoing flight parameters received. After the flight was completed, data recorded during its course was uploaded to the Operator Station. This included complete data, such as complete ECG graphs for the flight, which due to their size were not transmitted "on line", through the GPRS link.Research performed has made it possible to prove that the SMP-300 system is ready for use during training flights.

6. CONCLUSIONS

The developed SMP-300 system performs the full range of functions of a psycho-physiological and environmental data recorder, while ensuring monitoring of in-flight dynamic parameters in "off line" mode. The system also allowed recording of flight parameters calculated on the basis of recorded dynamic parameters and GPS monitoring, as well as flight trajectory mapping.

Research performed on the system has shown that the GPRS network can be used to monitor people moving using different modes of transport. The system allows "on line" tracking of key biophysiological and flight parameters from the ground, when flights are at a low altitude. There is nothing to prevent the SMP-300 system from being used to monitor people moving using different modes of land transport.

Experience in the preparation of people for the registration of biophysiological parameters has shown that the process is complex and requires experienced staff, which means that such monitoring cannot be used routinely. If routine recording is to be conducted, it is recommended that sensors be developed that allow the monitored person to put them on himself or herself.

The existing terrestrial mobile network does not allow “on line” registration to be performed during flights at altitudes in excess of 500 m. In the future the use of a satellite modem to transmit data may be considered, as this would extend the system with real-time viewing of parameters during a flight at higher altitudes.

BIBLIOGRAPHY

[1] MILLER B.A., BISDIKIAN C., Bluetooth revealed: the insider's guide to an open specification for global wireless communication, Prentice Hall PTR Upper Saddle River, NJ, USA, 2001.
[2] Bluetooth SIG, Specification of the Bluetooth System, v. 1.1, www.bluetooth.com, February 2001.
[3] (BLUEZ) Official Linux Protocol Stack, http://www.bluez.org/.
[4] STALLMAN R.M, Using GCC: The GNU Compiler Collection Reference Manual for GCC 3.3.1, Free Software Foundation. Inc, 2003.
[5] BROWN C, SUSE Linux, O'Reilly Media, Inc, 2006, ISBN: 0-596-10183-X.
[6] LOVE R, Linux Kernel Development Third Edition, ISBN-13:978-0-672-32916-6.
[7] CHAFFERJ J., Lerning JQuery, Packt Publishing, 2011, ISBN 978-1-84951-654-9.
[8] WELLMAN D., jQuery Tools UI Library, Packt Publishing, 2009, ISBN 1847199720.
[9] ULLMAN L., PHP for the WEB, Third edition, Peachpit Press, 2011, ISBN-10: 0-321-73345-2.
[10] MATTHEW N., STONES .R, Beginning Databases with PostgreSQL, 2005, ISBN-10:1-59059-478-9.