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Turbogenerator Mechanical Vibrations Telesurveillance System

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Abstract--**The paper proposes an autonomous integrated system performing remote monitoring activities for strategic objectives surveillance and risk prediction, focusing on monitoring of turbogenerator mechanical vibrations through communication channels. This system was designed to efficiently collect data regarding the turbogenerator mechanical vibrations and those induced in the turbogenerator support structure. The system proposed by this paper makes data collection much easier, the fixed sensors (accelerometers) can be interrogated remotely (as long as the system is aware of the location of the machine that launches the query). This system can interrogate up to 8 triaxial or 24 monoaxial sensors (with the possibility to extend this number of sensors). After a query is launched, the system makes the measurements requested in a sequential manner and returns the data. The results of measurements can be inspected visually and then saved for subsequent processing.**

***Index Terms*--data acquisition, GPRS, microcontroller, surveillance, turbogenerators, vibration measurement.**

I. Introduction

THE paper proposes an autonomous integrated system performing remote monitoring activities for strategic objectives surveillance and risk prediction, focusing on monitoring of turbogenerator mechanical vibrations through communication channels. This system was designed to efficiently collect data regarding the turbogenerator mechanical vibrations and those induced in the turbogenerator support structure.

The overall application to be implemented through the current proposed system is dedicated to be used in the Romanian energetic network and it is meant to stand as a reliable application to introduce computing and communications technologies to perform:

- continuous diagnosis / predictive monitoring;
- wireless sensors for permanent survey purposes;
- data acquisition and new sensors integration;
- remote access of data monitoring;
- integrated analysis;
- expert advisors.

The starting point for the proposed system was the actual need to perform surveillance activities at the foundation (building and equipments) of turbogenerators from specific sites in the energetic sector and, in particular, at the Cernavoda Nuclear Power Plant. The surveyed activities are set up on a former collaboration with Cernavoda with the support of the specialists from the Acoustics and Vibrations Laboratory (Mechanical Department, UPB). The proposed system followed the actual requirements and the actual work done till now. It is ready to be extended with new parameters to be surveyed and state of the art surveillance technology, communications and data management. At the same time further applications related to the overall concept are examined. All these parameters may have an important influence on the safety operating conditions of the overall power plant management concept and may indicate some malfunctioning incidents. Such pilot software system and data acquisition was proposed in this paper.

In the same time, new objectives and new applications needed to be designed and implemented in order to optimize the user access to a wide range of parameters of importance for plant safety, personnel, population and environment protection within the power plants were identified (Figure 1).

The proposed system introduces novel technologies and solutions for performing remote monitoring and data meaning and knowledge delivery activities. The proposed system will stand as a potential gateway to new applications enhancement and developing, opening the perspectives for future areas of appliance. The further releases and improvements of the proposed system will increase the efficiency and lower the production and exploitation costs. Note that this application had a number of varying and wide field applications from multiple parameters and objectives to be surveyed within the energetic sector. This application can be easily extended to environmental remote monitoring systems.

The system (Figure 1) connects monitored locations (**MLs**) to an intelligent surveillance and decision control centre (**CC**). The innovation aspects rely on designing and implementation of MLs, system integration, the use of the intelligent technology support, data processing and communication aspects, knowledge extraction and dissemination. The intelligent technologies are utilized in order to improve the problem solving potential of the system, to anticipating requirements and deal with targeted objectives linked to the areas of:

- novel sensor systems, structures, packaging and interrogation techniques;
- wireless communications;
- acquisition, processing and data management[1].

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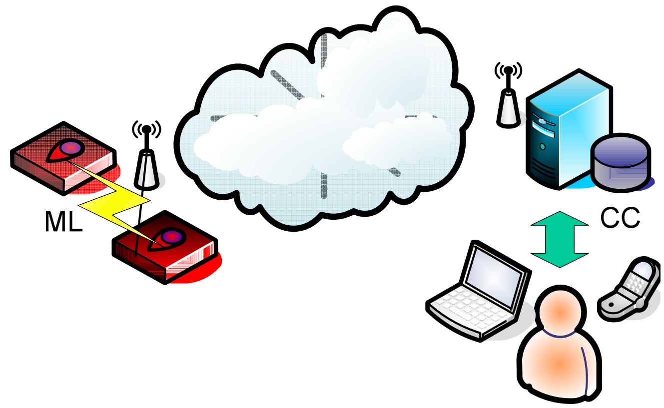

Legend	
Symbol	Description
	Control Center (application framework)
	Wireless / radio modem
	Communication medium
	Mobile application
	User
	Desktop/web data acces
	Remote Monitored Location (hardware, sensor integrated devices)
	Database
	Comm-link

Fig. 1 – Monitoring system concept

Till this time, data collection was done manually by taking samples from every point of measurement, using a sensor and a data acquisition interface connected to a portable computer (Figure 2).

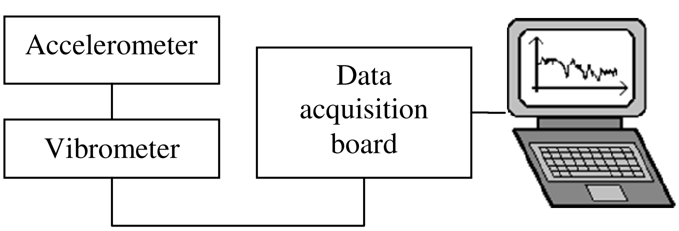

Fig. 2 – Vibration measurement platform used till now

The measurement procedure used till now means with other words the covering of the following steps:

- collection of analog data in the location to be monitored, from every point of measurement on each axis;

- amplification and buffering of the collected analog signals;

- analog-digital conversion using a data acquisition interface and storage of the digital samples on a laptop;

- processing of the stored data using specialized software [2],[3],[4].

Considering the actual means of performing the above mentioned activities, we identified those aspects that led us to the initiation of our research, such as:

- no presence of automatic data acquisition for an important range of parameters under surveillance interest;
- data acquired are processed in a vibrations and acoustics laboratory;
- time consuming measurement processes require specialized personnel;
- the existing software application requires new updates and no persistent databases or user access to the information are provided in addition;
- the technology used may be influenced by the specific medium where the measurements are set up to be carried out;
- the personnel require a minute assessing investigation, manually setting up the equipment, and long time exposure to hazardous areas.

II. General Architecture of the Telesurveillance System

The system proposed by this paper makes data collection much easier, the fixed sensors (accelerometers) can be interrogated remotely (as long as the system is aware of the location of the machine that launches the query). This system can interrogate up to 8 triaxial or 24 monoaxial sensors (with the possibility to extend this number of sensors). After a query is launched, the system makes the measurements requested in a sequential manner and returns the data. The results of measurements can be inspected visually and then saved for subsequent processing [1].

The block diagram of the proposed telesurveillace system is presented in Figure 3. The system consists of:

- a monitored location, based on multiple measurement points (Primary Acquisition and Processing Devices - PAPDs) respectively one Data Acquisition and Transmission Central Point (DATCP), which interrogates the measurement points, collects the results and sends them to the control center by means of a GPRS connection;

- a control center, which means a server controlled by a human operator [1],[4].

The involved accelerometers are FGP Sensors & Instrumentation FA1144-A1 (each of them including an amplifier), which measure on a single axis [5], so 1 - 3 accelerometers will be useful to fully characterize a measuring point if it is required. Only one device for each measuring point will be needed in the last case, if 3-axis accelerometers will be used.

Accelerometer data acquisition is done by the PAPDs, closely located to the sensors. Each of these devices contains an ATmega128 microcontroller [6], which integrates a 10 bit analog-digital converter, among other peripherals, which receives the signal from an integrated analog multiplexer. The data is subjected to preliminary processing and is stored in a local memory. The data is then sent to the DATCP using an RS485 interface.

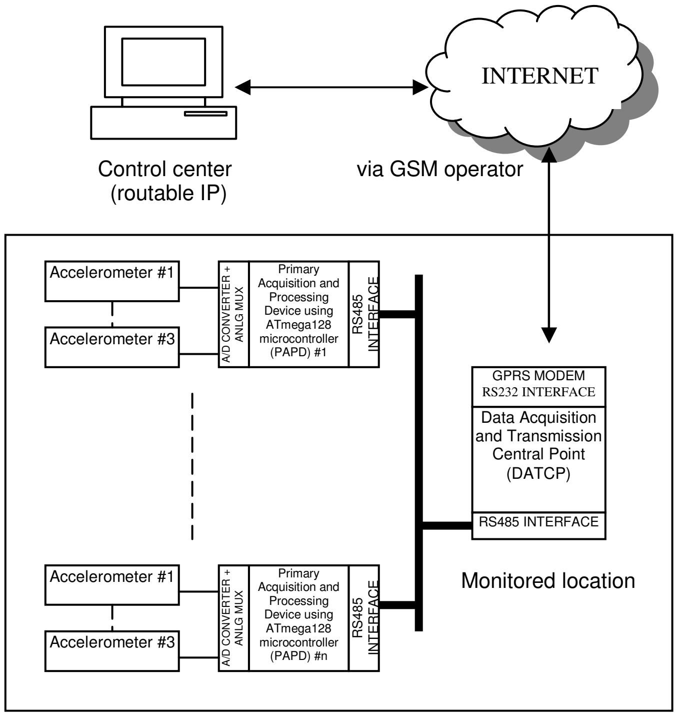

Fig. 3 – Proposed telesurveillance system – block diagram

The number of PAPDs that currently can be integrated in the system is 8, but it can be extended to approximately 32 (this limit is based on the performance of the RS485 multipoint communication interface) although this number may exceed the necessities of normal operation.

RS485 [7] is a balanced (differential) interface. The standard only defines the Physical layer, the signaling protocol is left to be implemented as the user requires. The RS485 is a multipoint type of communication and requires each node to have its own unique address. In a typical network there is one primary station and multiple secondary stations. The primary station controls the access of the secondary stations to the network.

In the case of the proposed system, the DATCP acts as a primary station and the PAPDs act as secondary stations. The DATCP sends messages (commands) through a wire pair and all PAPDs receive these messages. Each PAPD analyses the data received and only the device denominated by the message activates the RS485 line driver and responds. During this time, all the other PAPDs maintain their line drivers inactive. In this manner, all the devices can use a single wire pair to respond to the DATCP. So the connection cable between the DATCP and PAPDs depends on only 2 wire pairs.

The DATCP is also implemented through an ATmega128 microcontroller which assures the performances required by an industrial environment. Due to the functional conditions of the DATCP, storage devices like hard disks cannot be used. The DATCP does not store locally the acquired data for future use, but only acts as a buffer, temporary keeping the data in a volatile memory, before sending it via the GPRS communication channel to the control center.

The control center is a computer that has a routable IP address and runs specialized software. A dynamic DNS (Domain Name System) solution can be implemented if the IP address is likely to change.

III. Structural Blocks of the Telesurveillance System

As was mentioned above, the proposed telesurveillance system consists of a monitored location, based on multiple PAPDs and one DATCP, respectively a control center. Simply considering the control center as a server managed by a human operator, it is not necessary to pay a special attention to it. So the main attention will be paid only to those two blocks involved in the structure of the monitored location.

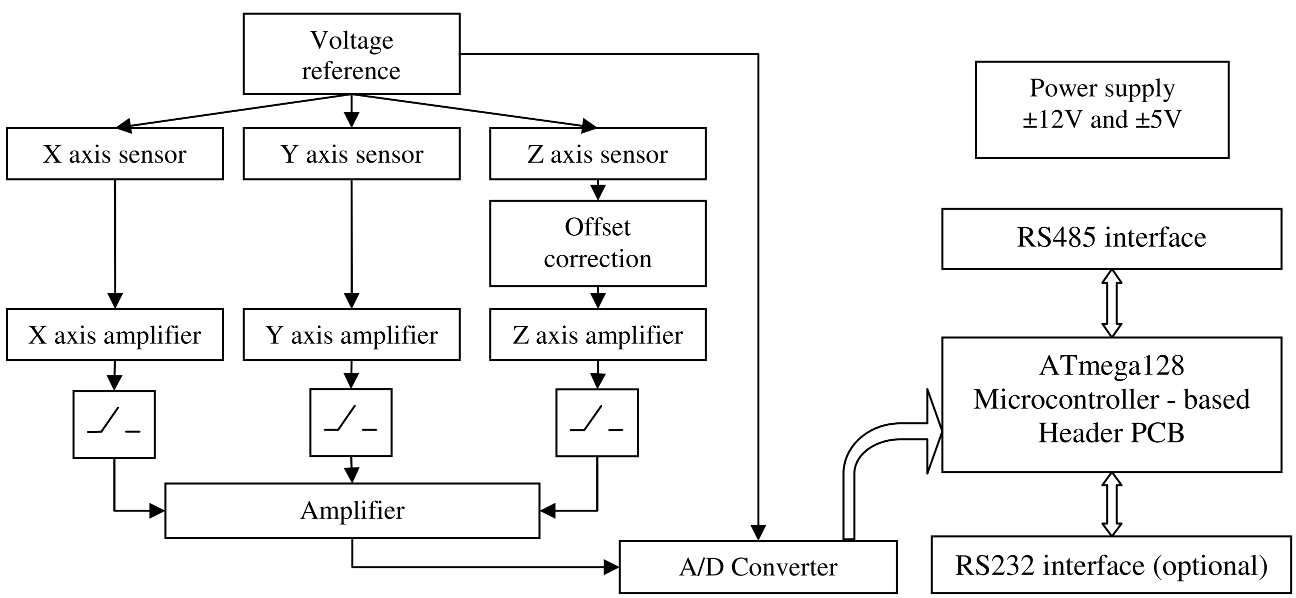

Fig. 4 - Block diagram of a PAPD

A. PAPD Structure

Each PAPD (Figure 4) is mounted in an adequate industrial environment housing and is linked with three axis sensors. The PAPD involves: a “Header – PCB”, based on ATmega128 microcontroller with two interfaces (RS485 for communication with the DATCP and RS232 - optional console port); an analog to digital converter with 12 bit precision; a sensors switching array followed by an amplifier; 3 sensor signal amplifiers with fixed gain; an offset correction circuit; a voltage reference and a d.c. power supply (connected to 220V a.c. voltage).

The “Header – PCB” contains an ATmega128 microcontroller with an additional 512KB RAM and memory control logic. The extra memory is used to buffer the acquired data before packetizing and sending via the RS485 interface.

There are two voltage adapters for the RS485 serial communication, one for each direction. One adapter is always in listen mode, and waits for a transmission from the DATCP. The other adapter is activated when the PAPD needs to transmit data, but only after the DATCP signaled that the PAPD has the right to do so. The line driver is immediately deactivated at the request of the DATCP or if this PAPD receives a message not dedicated to it.

The used analog to digital converter is embedded in the ATmega128 microcontroller [6] or is a stand-alone integrated circuit, chosen accordingly to the precision requirements of the measurement. In the designed system, the ADS7819 (12-Bit 800kHz Sampling CMOS) analog-to-digital converter was used. The maximum sampling rate greatly exceeds the needs of the system.

The voltage reference is used for the A/D converter and those three sensors. In this way, the measurements will be stable, regardless of the temperature or voltage variations. It is designed using a LM4140 (a precision micropower low dropout voltage reference) [8] and an amplifier that doubles its output. The result is a very stable 5V level.

The PAPD is based on the usage of FGP Sensors & Instrumentation FA1144-A1. Other different sensors can be adopted by making modifications on the PAPD.

The offset correction circuit is dedicated to adapt the usage of a sensor along the vertical axis, where de gravitational acceleration creates a zero offset. The same circuit can be applied on all axes to eliminate the zero offset, which has an important value, being uncontrolled otherwise. Thus such circuit is in fact an active high-pass filter with a very low cutoff frequency, which does not affect measurements at low frequencies.

The each sensor signal is amplified by a fixed gain instrumentation amplifier. The gain can be 10 or 100. The signal from a specific sensor can be selected using three relays, this one being applied to the final summing amplifier, which has an adjustable gain in the range: 1/10 – 10, depending on the installed sensors.

The power supply offers 4 voltage levels for the analog circuits: ±12V and ±5V. There is an additional +5V power supply dedicated to digital circuits.

The PAPDs do not need any intervention from the user. They are installed in fixed locations and are linked in a bus type configuration, according to the RS485 standard.

B. DATCP Structure

The DATCP (Figure 5) must be placed in a location which permits the installation of the GSM antenna necessary to the EZ-10 GPRS modem. This central point needs standard commercial 220V a.c. power. DATCP involves a “Header – PCB”, based on ATmega128 microcontroller with two interfaces (RS485 for communication with the PAPDs and RS232 – modem port) and a d.c. power supply.

The “Header – PCB” is based on ATmega128 microcontroller with an additional 512KB RAM and memory control logic. The extra memory is used to buffer the data received via the RS485 interface before sending data to the control center through the GPRS modem.

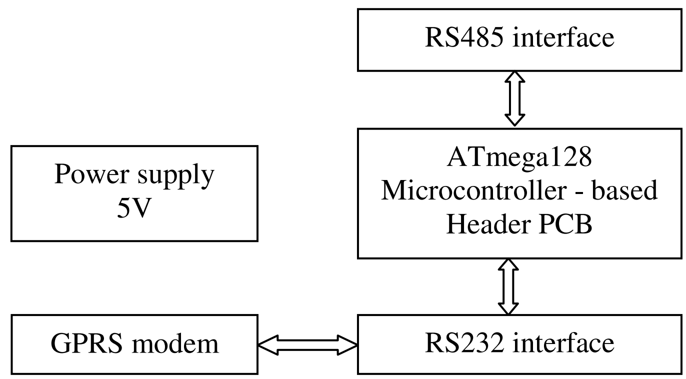

Fig. 5 - Block diagram of DATCP

There are two voltage adapters for the RS485 serial communication, one for each direction. One adapter is always in transmitting mode and is used to send requests to the PAPDs. The other one is set in listen mode and receives the replies.

The RS232 interface is dedicated to communicate with the GPRS modem. Such a modem requires a controlling device able to handle a limited V.24 implementation such as: RTS, CTS and, highly recommended, DCD lines. This requirement is justified by the fact that software flow control is not applicable. The GPRS modem is an EZ-10 type, based on Telit GM862 [9],[10].

The EZ-10 is a Dual/Tri band GSM/GPRS/PCS (EGSM900/1800MHz) wireless modem terminal based on the GM862GSM/GPRS/PCS technology. Depending from which type of GM862 module is embedded on the main board, the EZ-10 is capable for voice, data, fax, GSM, SMS, GPRS and PCS applications. The EZ-10 is fully compliant with ETSI GSM Phase 2+ specifications (Normal MS) and it allows remote control by AT commands (GSM 07.07 and 07.05) and the connection to host controller through RS232 standard serial port. All interfacing is done by 4 connectors placed on the front and rear panels [11].

The DATCP does not need any intervention from the user. It is installed in a fixed location, situated centrally on the RS485 bus configuration. The device may also be installed at one end of the bus, without affecting communication performance.

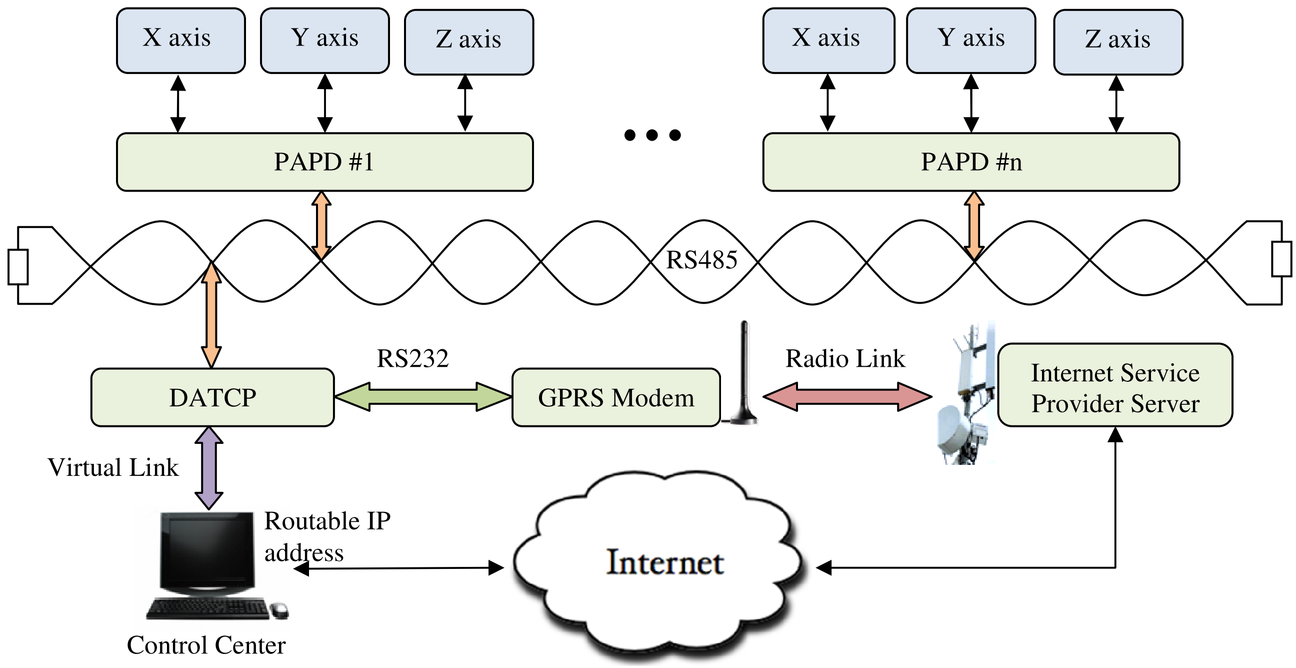

Fig. 6 – Telesurveillance system functional diagram

IV. Functional Considerations Related to the Telesurveillance System

After supplying the system, the PAPDs pass through a small initialization period (less than a second) and then switch to a waiting state. In such state, these devices receive RS485 communication interface commands from the DATCP. As soon as they receive a valid request, they will start the measurement process (Figure 6). For each measurement, each PAPD will cover the following steps: selects the requested axis; runs a test to determine the amplifier gain (10 or 100); acquires data during 10 seconds and stores them into the RAM; packetizes the data and sends them through the RS485 interface.

The DATCP has a longer initialization period than the PAPDs (up to about a minute), enough to properly initialize the GPRS modem, activate the GPRS context and then switch to the data exchange mode, which creates a virtual link between the control center and the DATCP. In this state, the DATCP starts periodically signaling its presence to the control center (server). In this way, the connection will be kept alive and the server will know the IP address and port of the DATCP, so the server will be able to interrogate the central point. Note that the server must have an external (routable) IP address, and this address must be stored in the configuration of the DATCP.

Upon a receiving request from the control center, the DATCP decodes the request and sequentially sends requests to each PAPD which needs to be engaged through the RS485 interface. If the engaged PAPDs respond correctly, the DATCP waits for data packets. Each packet is checked and the content is placed in the RAM. The data is then packetized in a GPRS format and sent to the control center.

The server application interface allows the operator to: install sensors; add a name and description of each of them; start the interrogation (partial or total) of the sensor system; view the acquired data; save the results in a format suitable for subsequent interpretations; access previous saved results for viewing.

The proposed system carries out automatically, by remote command, the former first 3 steps involved in the classical measuring method. The digital data are transmitted to the control center, where they are processed and stored in files using the same format used in the former procedure (for the compatibility of the new method with the older one). Data processing is carried out in the same fashion as in the classical method.

V. Conclusions

This paper is based on the results of CNCSIS contract number 514. Key aspects for the searched system are:

- The technology used in MLs assures well-functioning, having in view the special environmental characteristics where those will be mounted. We are particular referring to the possibility of adapting the technology to be used according to the environmental particularities (e.g. radioactive or chemical fluctuating medium);
- Process management (MLs pooling tasks, remote decision, etc);
- Data communication management between remote devices and server (remote data process, management of communication connections). As we previously mentioned, the solution used met special requirements imposed by the medium within the modems operate;
- Novel interrogation techniques were correlated with the acquisition system, performing a smarter sensor

interrogation based on a set of criteria;

- Parameters modeling and safety decision support which provided data mining and monitoring capabilities. Recent results have discovered very useful patterns to predict component failures and detect abnormalities;
- The need to improve the flexibility of the decision taking algorithms. We seek out to increase the systems flexibility by using experimental intelligent decision mechanisms. The solution may consist of software decision criteria, mainly according to the principles of artificial intelligence.

The research concluded with the construction of an experimental model, which was tested in the Mechanical Vibrations Laboratory of "Politehnica" University of Bucharest. The same model will soon be tested in a real industrial environment, inside a thermal power station in Bucharest. The final step is to test it inside the Nuclear Power Plant at Cernavoda.

VI. References

[1] V. Croitoru, T. Voica, A. Grigore, B. Toader, *Sistem experimental de telemonitorizare a vibrațiilor mecanice ale agregatelor*, Raport tehnic – faza 2– GR. 49/2008, cod CNCSIS 514, UPB, București, 2008.

[2] M. Angelo, *Vibration Monitoring of Machines*, Technical Review, Bruel & Kjaer, No.1, 2000.

[3] J. T. Broch, *Mechanical Vibration and Shock Measurements*, Bruel &Kjaer, 2000.

[4] V. Croitoru, I. Magheti, M. Magheti, T. Voica, *Comportarea în exploatare a fundațiilor şi a turbogeneratoarelor aferente centralelor electrice, tehnici de măsurare a vibrațiilor,metode şi proceduri privind culegerea şi transmiterea datelor*, Raport tehnic – faza 1– GR. 18/2007, cod CNCSIS 514, UPB, Bucureşti, 2007.

[5] *FA1144 Series Miniature Accelerometer*, FGP Sensors & Instrumentation, 2006, http://www.fgpsensors.com/pdf/fa1144_ex.pdf

[6] *ATmega128 Datasheet*, Atmel Corporation, 2008. Available: http://www.atmel.com/dyn/resources/prod_documents/doc2467.pdf

[7] Leroy Davis, *RS-485 Bus* http://www.interfacebus.com/Design_Connector_RS485.html

[8] *LM4140 High Precision Low Noise Low Dropout Voltage Referance*, National Semiconductor, 2005

[9] *Easy GPRS User Guide*, 80000ST10028 Rev. 1 - 14/03/07, Telit wireless solutions

[10] *Application Note 83 – Fundamentals of RS-232 Serial Communications*, Dallas Semiconductor, 1998, http://ece-www.colorado.edu/~mcclurel/dan83.pdf

[11] *Telit EZ10-PCS/-GPRS/-GSM Product Description*, 1vv0300653, Rev. ISSUE#0 - 06/07/04, Telit wireless solutions

VII. Biographies

Victor Croitoru (M'1990, SM'97) was born in Bucharest, Romania, on August 17, 1943. He graduated from the Polytechnic Institute of Bucharest and received his Ph.D. degree in Telecommunications from Polytechnic Institute of Bucharest, Romania, in 1974. He joined the Department of Telecommunications, Faculty of Electronics, Telecommunications and Information Technology, "Politehnica" University of Bucharest as an Assistant Professor in 1967, where he is now a full professor. His research interests focused on communication techniques, intelligent terminals, voice data integrated transmissions, programmed logic terminals testing, telephone terminal integrated sensory keyboards, personal communications, network management.

Dr. V. Croitoru is currently an associated editor of Revue Roumaine des Sciences Techniques, Serie Electrotechnique et Energetique, Romanian Academy Publishing House, respectively of AGIR Publishing House. He served as the chairs/co-chairs of some national/international conferences (e.g. IEEE ICT 2001, Communications 2000/2002/2004/2006/2008), and has received some educational/research awards (e.g. "Traian Vuia" Romanian Academy Prize, National Order "Loyalty in Serving the Country – in the position of officer", etc.). Dr. Croitoru is currently member of some scientific and technical academies and professional associations (e.g. corresponding member of American Romanian Academy of Arts and Sciences, corresponding member of Romanian Technical Sciences Academy, etc.) and Ph.D. advisor. He is a Senior member of IEEE Communications Society.

Tiberiu Voica was born in Bucharest, Romania, on November 27, 1958. He graduated from the Polytechnic Institute of Bucharest, and received his diplomat engineer degree in Applied Electronics from Polytechnic Institute of Bucharest, Romania in 1983. He is with S.C. MarcTel SIT SRL, as a scientific researcher since 2003. He is also involved in "Politehnica – MarcTel Integrated Communications" Research Laboratory, situated in the "Politehnica" University campus. He was with IPA (R&D Automation Engineering Institute) and Abacus SRL for 20 years, with "Politehnica" University of Bucharest (as an associated professor's assistant) for 2 years. He brings extensive experience in data acquisition and transmission. His main interest is in the area of microcontroller-based systems, and mobile stations data acquisition through a GPRS service. He is a Ph.D. student.

Adrian Grigore was born in Bucharest, Romania, on January 30, 1986. He is currently a senior year student with the "Politehnica" University of Bucharest, Faculty of Electronics, Telecommunications and Information Technology, Networks and Telecommunications Software specialization branch. His main interests are in the areas of microcontroller-based systems, communications software and communication protocols.

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