# Technology based on FPGA circuits and simultaneous processing of signals with great dynamic over time

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**Abstract**: Nowadays according to the paradigm of the Industry 4.0, the IoT (Internet of Things) concept has moved very fast to the IIot (Industrial Internet of Things). This approach claims that the real time processing using a big data can cause a lot of problems on the communication level. This process fills the communication line and the processor with a high number of bytes. All these types of cases are in the field of industrial processes and must be done very fast. A good improvement can be done with the complex processing on the information source and also with the transfer just for the computed data. That means, obviously a low capacity of bytes. In this context, the innovation introduced by National Instruments Company, around 7 years ago with the NI PAC (Programmable Automation Controller) platform suppose an insertion of a FPGA circuit command between the architecture of the embedded processor system and the main data acquisition system. This improvement is useful for the big data processing systems where it has obtained parallel processing possibility for big capacity in fast time processing. In fact, this system is equivalent with a software program but at the hardware level. Also, it is proposed to develop the application and the implementation of the FPGA circuit in a graphical environment such as Labview FPGA Module from the National Instruments Company. This technology will be used to help the Vonrep Company from Targu Jiu, Romania and to monitor a series of processes within this company.

*Keywords:* FPGA, Vibration, Real-time, Parallel processing

## 1. INTRODUCTION

The fast development of integrated technology has led to the widespread development of the most diverse microprocessor system structures. However, one can mention a topical idea:“To implement a program, it's called skill, and to discover the optimal formula of the algorithm (mathematical function) of what a program should do, is really called research or design.” Without minimizing the importance of each craft, this statement can be reinforced by the fact that, at the level of the huge programming tools, which are linked to extremely diverse hardware systems, in the field of automation, the problem remains very difficult to solve. The design of the control algorithm leads to the "best decision" for ordering a process. Thus, complex-large processes are divided into a virtual way in simpler subprocesses that are easier to know (mathematically modeled) and obviously more intuitively controlled. In this way there is a decentralization of decisions/orders, which very closely approximates the idea of control towards the notion of real-time. Connecting the physical world to the virtual world in cyber-physical systems will have a great impact in the coming period on technologies, manufacturing processes and people. The notion of "Smart Industry" or "Industry 4.0" represents the transition from embedded systems to intelligent systems ("cyber-physical systems" or "smart embedded systems") that communicate with each other to achieve a much larger productivity task. At the same time, Industry 4.0 is a compromise between "DECENTRALIZATION" and "CENTRALIZATION" at the industrial production level, with the aim of generating productivity at a very high level. Communication between plants in a factory leads to the new smart factory concept. The merger of this large amount of on-line and off-line information leads to the development of well-documented control solutions that boast unimaginable performances just a few years ago (A. Harnoy 2003), (Jiménez F.J., De Frutos J 2005), (Karacay T., Akturk N. 2009), (Link A., von Martens H. J. 2004). In conclusion, "We Have Hardware", "We Have Software", "We Have Communication", we just have to see what we do with them and if the problem can be resolved.

The proposed (http://www.ni.com/compactrio/;web page of National Instruments Company), real-time acquisition and processing architecture is presented in Fig. 1. The configuration of this architecture is based on the Compact RIO system developed by National Instruments and presents an innovation at the level of digital processing. The innovative idea is based on the insertion between a system architecture with a microprocessor and the data acquisition system (CAN and CNA converters) of a FPGA (Field Programmable Gate Array Programmable Logic Array). This circuit allows numerical and parallel processing times to take place. Thus, this architecture allows the development of parallel numerical processing in a very short time, with very high performance at real-time numerical processing.

The components, software development, and real-time acquisition or processing technology processing technology of vibration signals will be described in the next chapters.

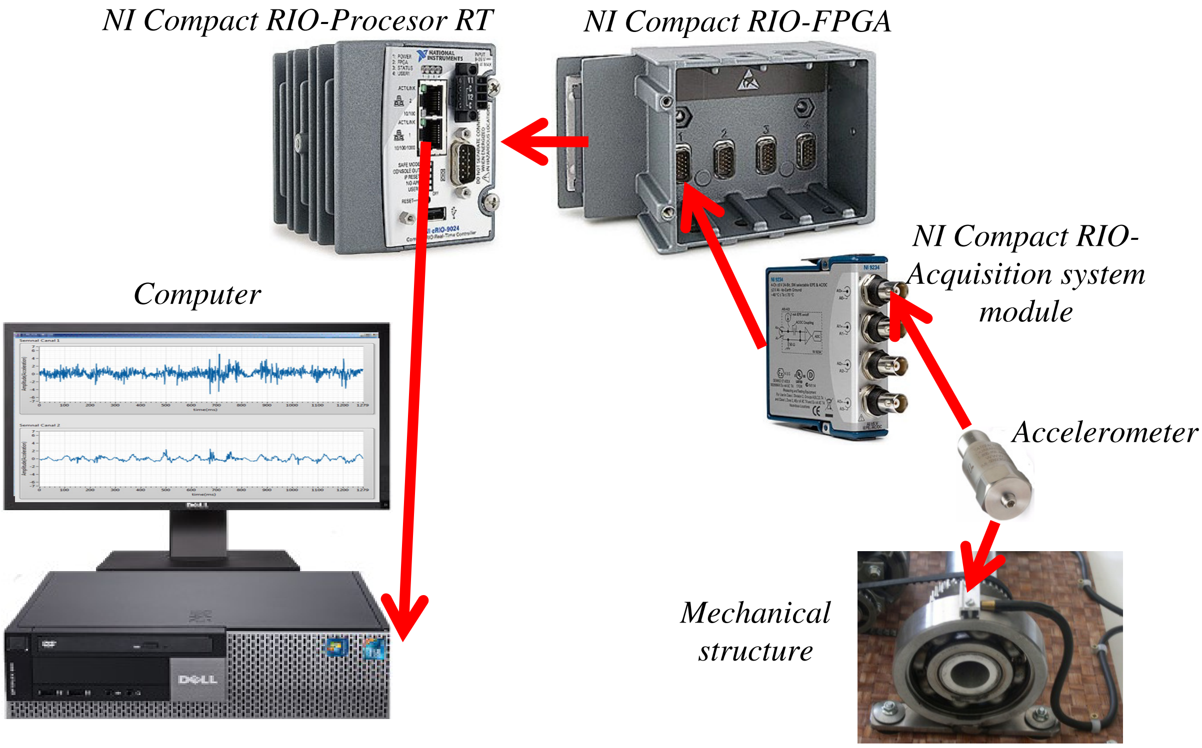


Fig 1. The architecture of the acquisition, parallel and real-time processing of vibration signals

## 2. REAL TIME PROCCESING AT SOURCE

The notion of Internet of Things (IoT) or, more recently, Industrial Internet of Things (IIoT) is based on the fact that all actual equipment is based on a microprocessor system that obviously can very easily communicate with others, as in Fig. 2 and Fig. 3.

If initially the idea has been extensively exploited in mobile, home-based, mobile applications, the current trend is to switch to industrial systems, as in Fig. 2 (image taken from www.ni.com). Nowadays the signal processing also offers a good theoretical start in the field of industrial processes.

The term "smart", although unique to biological systems, is beginning to gain increasing use into the industrial systems and not only (Smart grid, Smart City, Smart Machines, etc.). It was highlighted that only a very small percentage of data, from the multitude of existing data in the real world, can be processed. In fact, processes and storage units are flooded by the large amount of data to be processed (Buzdugan G., Fetcu L., Rareş M. 1975).

Fig 2. IoT (images from the NI website, www.ni.com)

As a result, with all the processing power of the current processors, only a percentage of around 5% can be processed, Fig.4.Was tried to overcome this problem by storing the purchased data and then processing it. Thus, the processing percentage increased only somewhere around 10%, Fig.5. The idea of connecting an FPGA circuit between the acquisition system and the real-time processor had the effect of real-time processing of data directly at their source, and the processing results obviously had a smaller number of bytes that could be easier to move in IOT space (www.ni.com/compactrio).

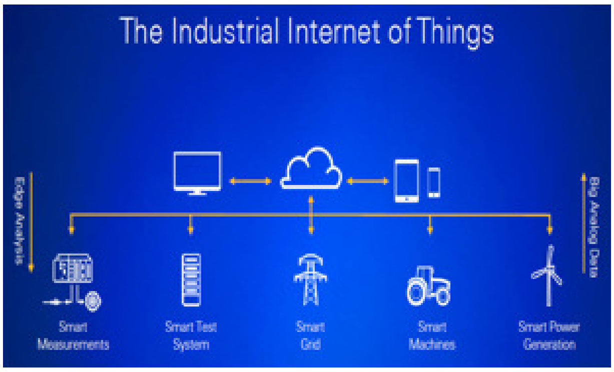


Fig 3. *IoT Scheme (images from the NI website, www.ni.com*

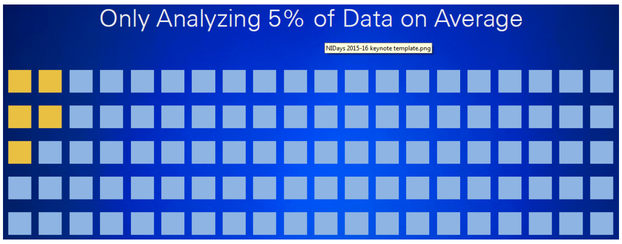


Fig 4. Real world data processing (images taken over NI Days Bucharest 2016)

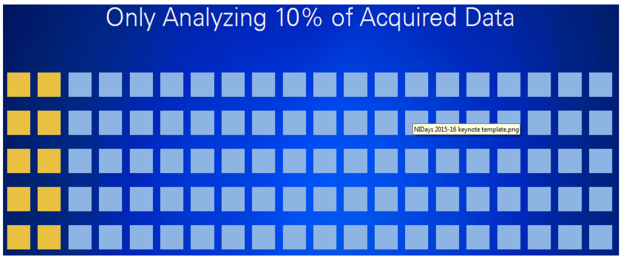


Fig 5. Real world data processing after storage

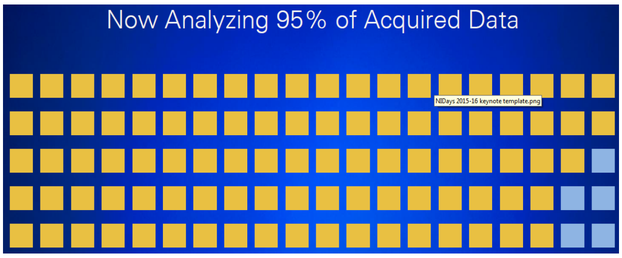


Fig 6. Real-world data processing using FPGA circuit technology as well

Nowadays based on the innovation introduced by National Instruments, processing can be achieved around 95% of real world data (http://www.ni.com/compactrio), Fig. 6.

In this context, Field Programmable Gate Array (FPGA) circuits are configurable, independent, configurable interconnected logical elements through a configurable routing network and switching matrix. This is hardware equipment that currently allows for the implementation of numerical signal processing algorithms. Unlike DSP (Digital Signal Processor), FPGAs are reconfigurable hardware solutions, Fig. 7 and Fig. 8.

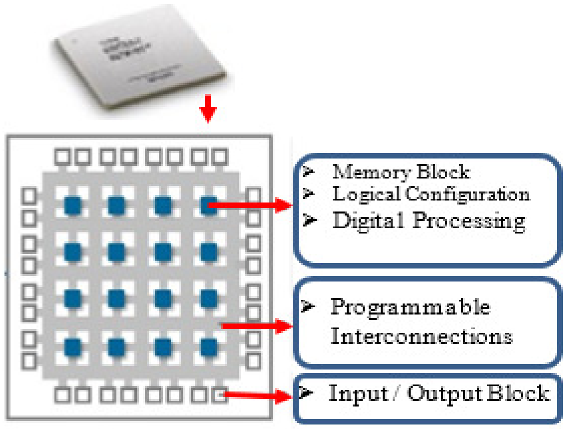


Fig. 7. Main Architecture of FPGA Circuits *(Popescu Marian, Runceanu Adrian 2009)*

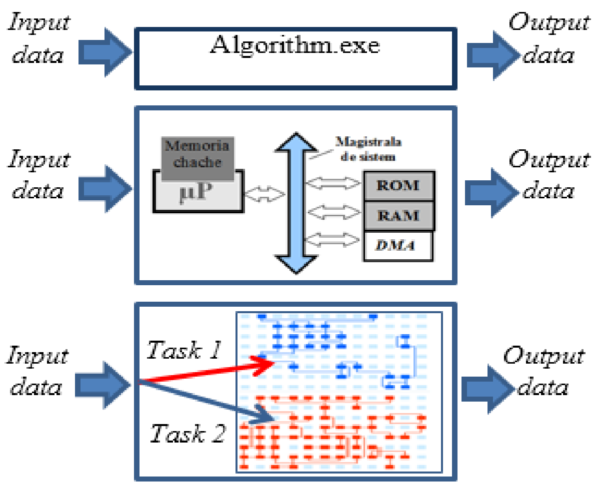


Fig 8. System architecture with microprocessor *(M.Popescu, A.Runceanu 2009)*

## 3. ARCHITECTURE DESCRIPTION USING FPGA CIRCUITS

The main advantage of FPGAs is the extremely high processing speed for a particular application, and the main drawback of the FPGA is high power consumption compared to DSP processor deployment. In this context, the idea of a SoPC (System on a Programable Chip) technology has emerged. This architecture allows the development of applications using microprocessors together with programmable hardware made with FPGA circuits. This technology was implemented more than 5 years ago by National Instruments on the NI PAC Platform (Programming Automation Controller) (I.M. Popescu 2014), and it can be programmed in the LabVIEW graphics development environment, and combines the reliability and robustness of PLCs (programmable Logic Controller) with the performance of a PC (Personal Computer) and with the flexibility of Field Programmable Gate Array (FPGA) circuits, Fig. 9, Fig.10.

The novelty consists in the possibility of complex processing of the hardware-acquired signals (I.M. Popescu 2014). Thus, the processing results are obtained in real time, which leads to the obtaining of complex decisions for the process. The architecture of the NI PAC Compact RIO system (http://www.ni.com at compactrio) is shown in Fig. 11.

Fig.9. Example of a PLC Siemens

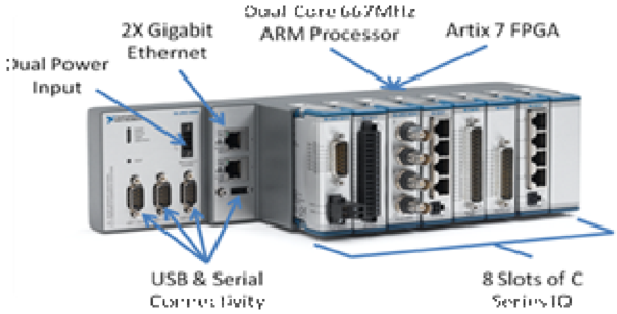


Fig 10. NI PAC Compact RIO

Generally, a microprocessor architecture requires a memory extraction instruction, decoding, processing, saving results in memory. In contrast, executing an instruction at an FPGA circuit is done directly at the hardware level, with the smallest processing time possible. At the same time, at the FPGA circuit level, parallel complexity processing is performed for the sampled information. For automated control actions, advanced control algorithms can be run directly into the FPGA circuit to minimize delays and maximize the speed of the adjustment loops.

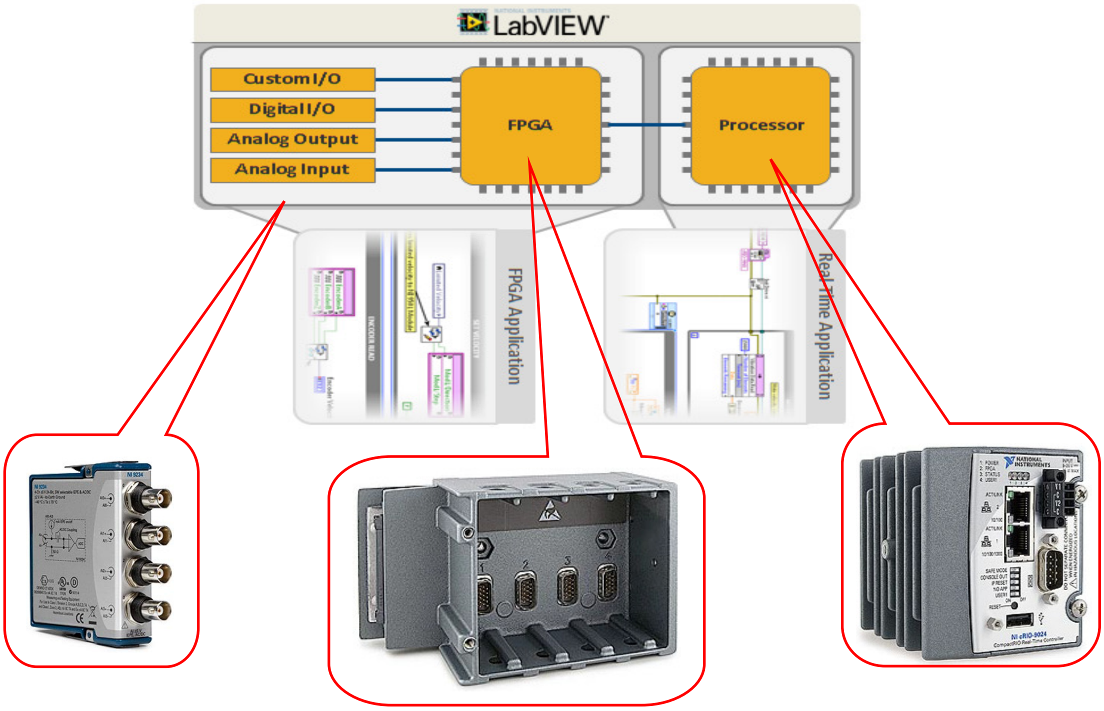


Fig 11. PAC Architecture - Programmable Automation Controller (http://www.ni.com/compactrio)

## 4. DEVELOPMENT OF THE SOFTWARE APPLICATION FOR PROCESSING

The structure of a software application is based on the development of a project in the LabView environment, as shown in Fig. 11. Which takes into account the hardware configuration. Corresponding to the FPGA circuit we have the *m_FPGA_function.vi* file that will be compiled and loaded into the FPGA circuit itself. The complex processes that can be made are: signal generation, interpolation functions, linear and nonlinear control, PID, matrix work, trigonometric functions, transformed Z, Fourier transform, various filters, timed loops, real time timers, and so on. The *m_RT_function.vi* file corresponds to the real-time processor at Compact RIO system level, which can perform complex operations specific to CISC processors. At the level of this processor, the results of real-time processing and the making of appropriate decisions and communication with a higher-level computing system are carried out.

In the application, the *m_PC_function.vi* file is the virtual tool that represents the application running on the host computer. It can perform additional processing of the sampled signals, the results obtained from the NI Compact RIO system, the processing, presentation at the level of a SCADA / HMI system of information, the management of a database.

The acquired vibration signals as well as the power spectrum were achieved at the NI Compact RIO - FPGA level, and through NI Compact RIO - RT Processor are sent via TCP / IP to the PC for display and possibly additional off - line processing

At the same time, in order to be sure that the difference between the output signals of the two measuring circuits corresponding to the two acquisition channels depends only on the wear degree of the bearings, permutations of the sensors and then of the load amplifiers between the channels to see if the differences also arise due to the imbalance of the measurement chains. Test results showed that the "wear" bearing generates vibrations with larger amplitudes than the "good" bearing.

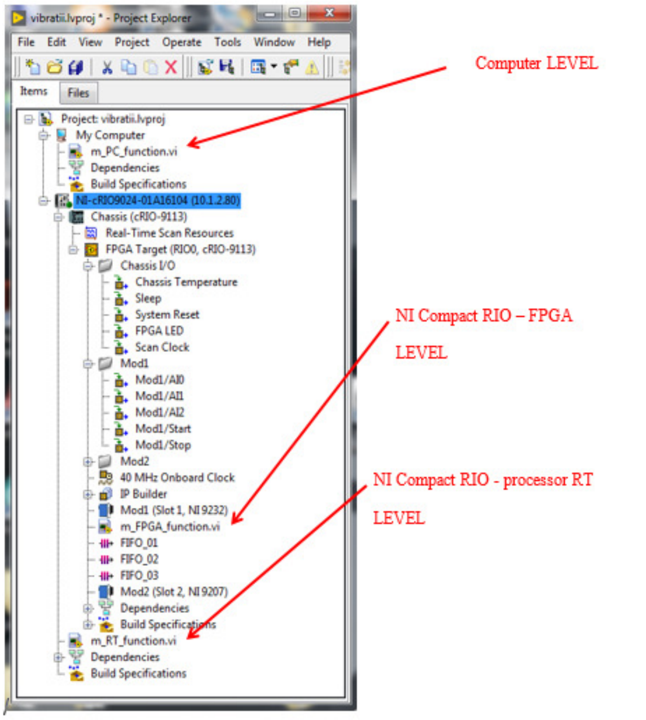


Fig. 12. Software application for acquisition in real time and parallel processing

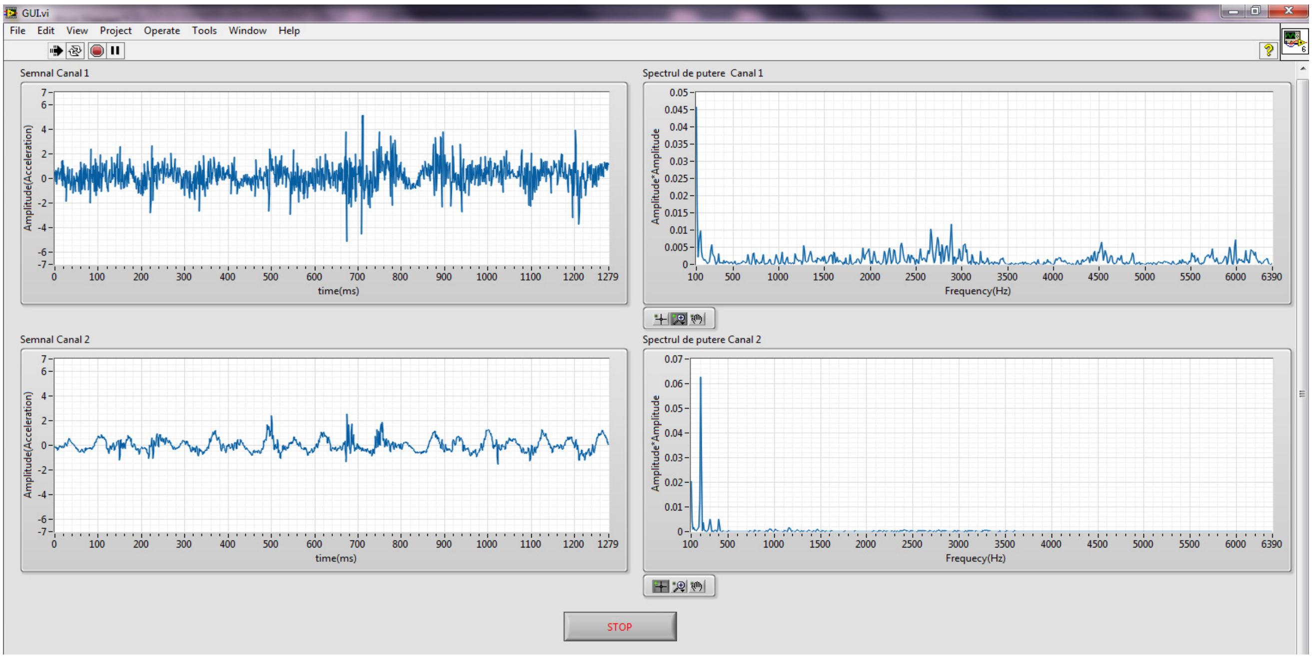


Fig. 13. Acquired vibration signals and power spectrum according to the two bearings: one new and the other with visible defects

This applications will improve the Vonrep S.R.L partner company expertise and the services portfolio; Achieving the results obtained in this project, represented by the information technology for processing the vibration software, which together with the hardware provided by National Instruments will allow to approach real-time acquisition and monitoring applications for vibrations. In this way it can be considered a real growth of the company's competitiveness by introducing new services. Another important result for Vonrep S.R.L. is the next possibility to continue research to develop predictive maintenance algorithms for various mechanical structures.

## 5. CONCLUSIONS

Numerical processing of vibration signals is a rather difficult issue that should take into account the following aspects:

1. The acquisition system must have strong real-time facilities because the vibration signal has rather high dynamics.
2. Another problem is the fact that most of the mechanical systems generating vibrations have imperfections in their structure, plus the fact that vibrations in a mechanical structure have more degrees of freedom and transmission speeds through the structure.
3. Vibration transmitter introduces distortion of signal amplitude and phase distortion.
4. Any acquisition system (including transmitter) and vibration signal processing requires laborious calibration on stands especially designed for a particular application type.
5. The analysis and on-line processing of vibration signals are very difficult to achieve because in a machine, the point where the vibration measurement is performed is generally deviated from the processing system, and the connection cables enter additional distortion.

A practical way of processing the vibrations in order to perform a maintenance of the respective machine, is hard on real time processing of the signal for a "good" mechanical structure. This processing can be taken as a comparison reference to other identical structures.

## 6. FUTURE WORK

Further on the research activity presented will develop the project in the following directions:

1. Detailed analysis of some parameters such as acceleration, speed, amplitude in the context of a complete system.
2. Implementation of the Fourier transform and deconvolution method for vibration signals.
3. Development of an FPGA chip processing technology for calculating the inverse signal on noise and anti-noise in the audio domain.

## ACKNOWLEDGMENT

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI - UEFISCDI, project number 116CI 2017, PN-III-P2-2.1-CI-2017-0167, within PNCDI III. (Vonrep SRL and University of Craiova).

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*http://www.ni.com/compactrio/ ; web page of National Instruments Company*