Partnerships Program

Joint Applied Research Projects (PCCA)

Summary of the Research Report

Work package: I

Phase title: *Analysis and evaluation of the existing methods, techniques and algorithms*

Project title: *Experimental model for change detection and diagnosis of vibrational processes using advanced measuring and analysis model-based techniques.*

Cod: PN-II-PT-PCCA-2013-4-0044

Acronym: *VIBROCHANGE*

Main authority: (UEFISCDI) – *Executive Unit for Financing Education Higher, Research and Development and Innovations and Creativity.*

Contractor: *"Dunărea de Jos" University of Galaţi*

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Consortium:
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P1 - INCD în Informatică Bucharest, Popescu Dan Theodor, Team Lider P1
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P3 - TeamNet Engineering SRL Bucharest, Roman Nicu, Team Lider P3

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Phase #1: The summary of the Research Report

1. Introduction

The project considers the *Change Detection and Diagnosis problem* (CDD) in vibrational processes using advanced measuring and analysis techniques model-based. The vibrational processes are characterized by vibrational phenomena, which include mainly, as effect, mechanical vibration signals, resulting in normal or abnormal operating.

It is an important trend concerning the replacement of the systematic procedure of maintenance of machinery and equipment's by conditional maintenance strategies, based on continuously or selective monitoring of the process, with the scope of detection of abnormal behaviour and to avoid catastrophic events of economic or ecological nature. In this context, early time detection of abnormal behaviour of systems seems to be a necessary solution, possible and efficient, in rapport with a right working mode description, without artificial excitation, change of the working regime or breaks.

The general objective of the project is to build an experimental model for CDD with application in vibrational process monitoring, using advanced measuring and analysis techniques model-based. The specific objectives are: (O1) Development, implementation and validation of new methods, techniques and algorithms for CDD; (O2) Optimization of classical algorithms for CDD; (O3) CDD information fusion coming from and in time of process monitoring; (O4) Development of a CDD software library, which will implement both classical (known) methods and optimized and new developed ones during the project running; (O5) Development and testing of an experimental model for CDD, with commercial features, hardware and software, which will use the results obtained during the project, under all aspects: theoretic, algorithmic and methodologic.

The monitoring of the vibrational processes will consider, in project, another two waves, which are naturally generated and accompanying, partial or complete, continuously or discontinuously, the mechanical vibrations: (1) acoustic waves, inside the audio spectrum; (2) ultrasound waves, with frequencies up to 100 kHz. The project looks on information analysis and processing generated by the set of three presented sources, and to information fusion, for the best decision. The approach will allow the improvement of the process monitoring, more efficient and matched to the considered scope, in rapport with non-fusion, and will be a novelty on national level and one of the few approaches in international area.

The project is sustained by the following consortium: "Dunarea de Jos" University of Galati (Coordinator); National Institute of Research and Development in Informatics, Bucharest (Partner 1); National Institute of Research and Development in Mechatronics and Measurement Technique, Bucharest (Partner 2); Teamnet Engineering SRL of Galati (Partner 3).

The project will build two products, both new, original and international competitive, which will provide solutions to CDD problems of vibrational processes. P1: A program library, as Toolbox of Matlab, which will implement the best algorithms for CDD, using both classical and advanced techniques, as those based on multiresolution analysis, information fusion and soft computing. The product will build a reference for CDD problem and will allow the performance evaluation of new algorithms to the old ones. By using real data from vibrational processes, CDD benchmarks will be proposed; P2: an experimental model, having a CDD software application as basis, to be used in monitoring of some pilot processes, in laboratory, and of a complex industrial process. The physical model will be the basis to launch full commercial products for various processes and markets.

The presented results, as well as the support systems resulted (e.g. measuring and testing systems) will rise the procedural algorithmic level for the improvement of industrial process monitoring, enhancing their operational safety.

2. The results of the 1st phase

The main results of this phase were generated by the analysis activity made in the last six months of the year 2014. These are:

➢It performed an analysis of various approaches to detection and diagnosis technology of machinery with and without model, and were generated some extensions of these approaches that appeal to the model type or wavelet neural networks and hybrid dynamic numerical / symbolic models. Based on this analysis has submitted a possible organizational structure associated software a general approach for the detection and diagnosis.

➢As for monitoring rotating machines (as well as complementary) aim to determine a "signature" of them, which is not affected by noise interference generated by machines operating in the vicinity, or the environment, was used spatial diversity and redundancy in multi-channel vibration measurement machine to separate the "signature" disturbing noises monitored machine.

➢Given the presence of instant mixes and convolution, the operation of rotating machines, vibration components to separate, own car which is subject to monitoring, to specific techniques called independent component analysis (ICA) as the main tool of separation "blind" sources (BSS) to be used for the purpose of reconstruction "signatures" of individual sizes or component will be subject to proper detection (possibly subject patent proposal).

➢Non-stationarity detection can be done by measuring the system response to various types of excitations or using higher order statistics and spectra measurements. A particular form of non-stationary, cyclo-stationarity can be observed in rotating machines, especially in the operation of bearings and gearbox bearings. For analysis of the various phenomena of nonstationary signals and extracting features subject analysis and diagnosis will use time-frequency analysis combined with other procedures parametric modelling and detection (possibly subject patent proposal).

➢Theoretical and algorithmic detection and diagnosis problem (CDD) was formulated, which provides the overall framework for developing applications in the field.

➢As regards the detection of changes in the average value of a signal, in addition to basic tests that uses likelihood ratio, were presented different ways and use their properties for sequential and non-sequential, parallel with the introduction of other types of detectors which are distinguished by the simplicity of use (derivative filters, detector Shiryaev, CUSUM detector Hines).

➢Detect changes in signals, as an essential element in monitoring procedures of machinery and technological equipment, makes use of parametric models (AR and ARMA) in order to discriminate signal characteristics before and after the change takes place. This phase aimed to analyse the main methods and techniques from the literature in this area: techniques that appeal to the aggregate amount of innovations, techniques Bayesian, maximum likelihood, model order selection, various forms quadratic, Kullback information, "distance" Cepstral, and other measures of this "distance", which will be the basis for the development of new methods and techniques to be implemented within CDD library programs and experimental model.

➢The problem of change detection in dynamical systems, which enjoy a wide space research report, is an extension of changes in signal detection problem, and in addition to an overview of existing methods and techniques in relation to connections between them are different, with consideration of diagnostic heuristics and methods of extracting specific characteristics of vibration signals, which lead to the robustness of this category of methods and techniques. It makes use of both state models and input-output model of the system. In the first case, using techniques based on information redundancy, multiple models and calculation innovations associated with centering tests and their independence (SPRT, GLR). In the second case, further developing the test statistics in time and frequency, type ARMAX models, the approach in the frequency domain is characterized by ensuring the robustness of the detection procedure unshaped dynamics of the system, or to the effect of disturbances. It also presents a procedure for detection of changes in modal characteristics of mechanical systems of great utility in their monitoring systems. The emphasis in this chapter is on issues of detection of changes in signals and systems dynamics, although some references are made and how the information obtained can be used for diagnostic purposes. The proposed approach provides a robust framework for monitoring processes and technological facilities, but not a fully automatic procedure to monitor them.

➢In some cases, the effect of a change in the system dynamics observed variables is direct and simple, in which detection of a change effort focuses on establishing a rule of decision. In other cases, the effect of such changes is manifested in a more complex way (indirect). In the latter case, there are usually two problems: (1) the observed signal processing in order to simplify the rise and effect change and (2) the definition of statistics and decision rules in terms of outputs processed. The first problem is an important direction in the development of robust detection methods with uncertainty of dynamic models used. This research highlights these issues and provides both direct methods, obtained by direct processing of signals in process and indirect methods, based transformations for both detection and diagnostics.

➢Given the increased interest, in some cases, for the detection and diagnosis using intelligent recognition techniques, including where information is provided by vibrational signals, the research includes several algorithms CDD in this category. The utility of this class of algorithms is proved especially if they do not have accurate analytical models, and make use of knowledge-based models, designs or models fuzzy neural models generally results in processes of training (learning). In addition, neural networks can be used in waste classification and fuzzy logic can be used in decision-making.

➢

➢ Were identified more advanced methods that can be used in CDD problems. Thus, genetic algorithms are proposed that can be used in a wider framework of optimization problems, and to solve sub-problems of the CDD. Methods based on rare representations (sparse) enable the development of new approaches and wine to complement traditional methods presented, providing solutions for transient signals, or those that occur intermittently.

➢From the analysis revealed that there is an increased interest in the use of different sources of signal (vibration, acoustic and ultrasonic) in developing solutions to CDD. The research report addresses this issue and presents several solutions that will be the subject of next steps, including the implementation of the experimental model.

3. Published papers

1. Theodor Dan Popescu, Signal Segmentation Using Changing Regression Models with Application in Seismic Engineering, *Digital Signal Processing*, Elsevier, Vol. 24, No. 1, 2014, pp. 14-26, ISSN: 1051-2004, DOI:10.1016/j.dsp.2013.09.03.

2. Dorel Aiordăchioaie, On Quick Change Detection in Finite State Spaces based on Sequential Decisions, *IEEE International Conference on Electronics, Computers and Artificial Intelligence, (ECAI-2014)*, Bucharest, 23-26 October, 2014, pp. 17-22..

3. Dorel Aiordăchioaie, On Quick-Change Detection based on Process Adaptive Modelling and Identification, *The 12th IEEE International Conference on Development and Application Systems DAS-2014*, Suceava, Romania, May 15-17, 2014, pp. 25-28.

4. Dorel Aiordăchioaie, On entropy-based measures for change detection, *The Annals of "Dunarea De Jos" University of Galati*, Fascicle III, 2013, 36(1), ISSN 1221-454x, Electrotechnics, Electronics, Automatic Control, Informatics, pp. 43-48.

5. Dorel Aiordăchioaie and Mihaela Andrei, On Change Detection for Improved Reliability, *The 19-th IEEE International Symposium for Design and Technology in Electronic Packaging (SIITME-2013),*Galati, 24-27 October 2013, pp.251-254.

6. Dorel Aiordăchioaie, Signal Segmentation Based on Direct Use of Statistical Moments and Renyi Entropy, *The 10th International Conference on Electronics, Computer and Computation (ICECCO'13)*, 7-9 Noiembrie 2013, Istanbul, Turkey, pp. 359-362.

7. Dan Theodor Popescu and Aiordăchioaie Dorel, Signal Segmentation in Time-Frequency Plane using Renyi Entropy - Application in Seismic Signal Processing, *The 2nd International Conference on Control and Fault-Tolerant Systems, SysTol-2013*, October 9-11, 2013, Nice, France, pp. 312-317.

Proposed papers :

1. Th. D. Popescu, BSS-Based Fault Detection and Diagnosis of Rotating Machinery, *The 3rd International Conference on Advances in Computational Modeling and Simulation*, July 13-15, 2015, Kunming, China.

2. Th. D. Popescu, A New Statistical Approach for Discrimination of Model Parameter and Noise Variance Changes, *The 10th Asian Control Conference* (ASCC 2015), 31 May – 3 June, 2015, Sabah, Malaysia.

Galați, 12.12.2014

Project Manager,

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