Diagnostic features space construction using Volterra kernels wavelet transforms

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Bucharest is Romania’s capital and the biggest financial, administrative and cultural centre. According to Eurostat, the Bucharest population has around 2,151,880 residents, being the 10th largest city of the European Union. Bucharest's crime rate is rather low in comparison to other European capital cities.

Bucharest hosts the biggest population of students in Romania and some of its largest universities.

Bucharest’s eclectic architecture is a mix of historical (neo-classical), interbellum (Bauhaus and Art Deco), Communist-era and modern. In the period between the two World Wars, the city's elegant architecture and the sophistication of its elite earned Bucharest the nickname of "Little Paris".

Bucharest is situated on the banks of the Dâmbovița River, which flows into the Argeș River, a tributary of the Danube.

The old town Bucharest is located at the very centre of the city. The area is home to many art galleries, antique shops and coffeehouses. At the centre of the historic area, the remains of the Old Princely Court (Curtea Veche), built in the 15th century by Vlad Țepeș, also known as Vlad Dracula can be found. The old city centre is now under partial renovation works.

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Message from the IDAACS'17 Co-Chairmen

It's our pleasure to invite all of you to participate in the 2017 IEEE 9th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS), www.idaacs.net, which will be held in Bucharest, Romania, 21-23 September, 2017.

The main goal of IDAACS'2017 is to provide a forum for high quality reports on the state-of the-art Theory, Technology and Applications of Intelligent Data Acquisition and Advanced Computer Systems as used in different areas. A family of IDAACS Workshops has already been created since the IEEE 1st IDAACS Workshop was held in Foros, Crimea, Ukraine, July 1-4, 2001. After that the following IDAACS Conferences were held in Lviv, Ukraine, 2003, Sofia, Bulgaria, 2005, Dortmund, Germany, 2007, Rende (Cosenza), Italy, 2009, Prague, Czech Republic, 2011, Berlin, Germany, 2013, Warsaw, Poland, 2015. IDAACS satellite Symposiums on Wireless Systems (SWS) were held in Offenburg, Germany in 2012, 2014 and 2016 correspondigly.

The IDAACS'17 Conference is organized by IEEE Ukraine Section I&M / CI Joint Societies Chapter and the Research Institute for Intelligent Computer Systems, Ternopil National Economic University (TNEU) and V.M. Glushkov Institute of Cybernetics, National Academy of Sciences, Ukraine in cooperation with the Faculty of Automatic Control and Computers, University "Politehnica" of Bucharest(UPB).

It is supported and sponsored by IEEE Ukraine Section I&M/CI Joint Societies Chapter, TNEU, Faculty of Automatic Control and Computer Science of UPB, IEEE Ukraine Section, IEEE Romanian Section, Romanian Society of Automatic Control and Technical Informatics, Asti Automation, River Publishers, TÜV AUSTRIA ROMANIA and Festo, we express our deep gratitude to each of them.

The International Programme Committee of IDAACS'2017 is co-chaired by Dora Blanco Heras and John Kalomiros, many thanks to both of them for their constructive and fruitful work. Also we express our gratitude for all members of IPC. There were submitted the 348 papers by authors from the 35 countries. We would like to sincerely thank all the reviewers of the submitted papers, their names are listed in the proceedings and their contribution to the quality and success of this Conference is hereby gratefully acknowledged. As a result of the reviewing process the 213 papers were accepted for a publication in the Conference proceedings. All the presentations are organized into the 26 oral and the three poster sessions. Also we have the two plenary sessions with keynotes speakers Kay Uwe Römer, a Director of the Institute of Technical Informatics – TU Graz and Dan Cristea, a Corresponding Member of the Romanian Academy. We appreciate very much their contribution in the IDAACS'17 Conference.

Also many thanks to Vyacheslav Kharchenko, Ukraine who initiated a new Workshop Cyber Physical Systems and Internet of Things Dependability within IDAACS 2017, this Workshop counted the two sessions. Besides, the IDAACS 2017 remained its peculiarity providing the nine special streams with 15 sessions. The biggest streams are Advanced Information Technologies in Environmental, Co-chairs YuryKolokolov, Russian Federation and Kondo H. Adjallah, France and Cyber Security, Co-chairs George Markowsky, USA and Igor Kotenko, Russian Federation, three sessions per each. Also we thank very much Ioana Fagarasan, Dan Popescu and Grigore Stamatescu who created and co-chaired a new Special Stream in Smart Buildings and Smart Cities with the two sessions. Our gratitude to Carsten Wolff and Wolfgang Tysiak, Co-Chairs of the Special Stream in Project Management(with the two sessions) which became the integral part of the IDAACS conference since 2007, we pay tribute to unforgettable Peter Reusch.

Bucharest is the economic, cultural and administrative center of Romania and an important regional hub.There are 33 universities in the Bucharest area with 127000 students enrolled, over a third of the national total. Several important universities are mentioned such as the University of Bucharest, the Academy of Economic Studies and the University "Politehnica" of Bucharest. The city's profile as a technology hotspot is reflected by the large number of established multinational companies and an ecosystem of emerging local companies in the ITC field.

Finally we would like to thank all our friends and colleagues from the previous IDAACS' conferences as well as new participants for joining us in Bucharest to discuss the latest achievements in the fields of Intelligent Data Acquisition and Advanced Computer Systems!

Enjoy attending the IDAACS'17 conference and the charm and dynamic spirit of Bucharest!

Anatoliy Sachenko   Grigore Stamatescu

Dear participants of IDAACS 2017 Conference!

It's my pleasure to greet all of you attending the 9th IEEE Conference on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS) in the attractive city of Bucharest!

A subject of the IDAACS'17 Conference is hot enough because nowadays a domain of the advanced computer technologies and data acquisition systems continues to develop faster than other areas.

I am glad the number of IDAACS conference participants is growing that confirms the researcher's interest to this event. This time people from 35 countries are attending the IDAACS'2017 Conference and I believe the Conference will create the unique atmosphere for strengthening links between different teams, generating the new ideas, and intensifying the new international projects preparation. Obviously, it is very important for integrating the Ukraine and other Eastern European countries into the European and worldwide academic and science system.

I am very proud of the team from the Research Institute for Intelligent Computer Systems(ICS). Core staff of this team has been worked together for 32 years already. In past they have made the significant progress in developing the automated devices and systems for the defense industry of the former Soviet Union. Since the middle of 90th they reoriented their activities in western direction starting to run international projects. So far they made a significant impact completing many projects within the INTAS, CRDF, NSF, NATO, STCU, FP7 and bilateral programs. The ICS team works very closely with IEEE, created the IEEE Student Branch and the IEEE Ukraine Section I&M / CI Joint Societies Chapter. Moreover they are issuing the International Journal of Computing quarterly since 2012 which is indexing by Scopus Elsevier in 2016.

One more achieve of the ICS team is running the International IEEE IDAACS Conferences since 2001 as well as two satellite Symposiums on Wireless Systems within IDAACS since 2012.

Finally I'd like to express my special gratitude to Prof. Mihnea Costoiu, the Rector of University "Politehnica" of Bucharest and Dr. Grigore Stamatescu and the all Romanian team who hosted this remarkable event. I am sure that IDAACS'2017 Conference will be interesting for all participants and I would like to invite all of them for a future cooperation.

Sincerely,

Rector,
Ternopil National Economic University — Andriy Krysovatyy

Dear participants of the 9th International Conference "Intelligent Data Acquisition and Advanced Computing Systems"!

It is my pleasure to welcome you, on behalf of the University "Politehnica" of Bucharest (UPB), to the 9th International Conference on "Intelligent Data Acquisition and Advanced Computing Systems". We are truly glad to reunite some of the best experts in their respective fields.

The UPB encourages research and development projects, as well as other innovative education and cultural programmes, as part of our fundamental functioning. Topics focusing on information society are dealt with the same care and dedication as are the topics focused on energy-related issues and environmental problems. Whereas some business-related research concentrates on promoting entrepreneurial start-ups and improving the competitiveness of small and medium-sized enterprises, other research addresses social-economics and political policies, such as European and national labour market policies, or the effects of globalisation. Projects regarding the preservation of cultural heritage and projects from the field of design round off the spectrum of research and follow through the research-implementation cycle. Within Bucharest, Romania and Europe, the UPB works together with small and medium-sized businesses, unions, administrations, associations, research and training institutions, and many other partners in order to fulfil these objectives and goals.

The UPB offers an impressive range of study programmes through its 13 faculties, organising undergraduate studies in 15 fields with 66 distinct specialisations. Master studies are organised In 15 distinct fields with 97 specialisations, as well as PhD studies. The educational and research offer of the University "Politehnica" of Bucharest spans through nearly all areas of engineering such as: electrical engineering and computer science, automatic control, electronic engineering, chemical engineering and mechanical engineering as well as studies dedicated to innovation, entrepreneurship and business management. In order to ensure the highestteaching standards to the large number of over 28000 students the UPB angages a community of 1700 academic teachers in the educational process.

As I was informed, the IDAACS events have been organised regularly since 2001, their reputation increased year by year, the same as the number of participants. The large numbers of participants in this year show the quality the conference has reached over the years. It also ensures that the primary objective of the IDAACS conference is reached - to promote the international exchange of scientific and technical information in the wide area of theory, technology and applications of intelligent data acquisition and advanced computer systems, as used in measurement, automation, and scientific research, in industry and in business alike.

I am sure that this event will provide participants with an excellent opportunity to exchange ideas and information about their research findings and will give us all the opportunity to refresh personal contacts and establish new ones.

Finally I'd like to wish all of you a pleasant stay in Bucharest

With kind regards,

Rector,
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Diagnostic Features Space Construction using Volterra Kernels Wavelet Transforms

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***Abstract*—In this paper the problem of improving the reliability of nonlinear dynamic objects fault diagnosing is presented. Model-based diagnostics nonparametric identification method is used. Diagnostic models are constructed on the base of Volterra kernels wavelet transforms.**

The effectiveness of the suggested diagnostic models based on Volterra kernels wavelet transforms is analyzed on the basis of simulation model of nonlinear dynamic object.

Keywords—Volterra kernels; diagnostics efficiency; fault diagnosis; feature space reduction, wavelet transform.

I. INTRODUCTION

Nowadays the increasing of the control objects complexity while maintaining the dynamic and non-linear properties of systems, increased demands on precision and objectivity of decisions raise the problem of complex computing systems development. Such systems will ensure required characteristics and automate the monitoring process for different physical nature objects. Modern diagnostic systems are constructed on the base of new mathematical techniques [1, 2]. The scientific problem of creation, improvement and effective use of mathematical diagnostic models of controlled objects is actual and not fully solved.

The technical diagnostics methods, developed on the basis of controlled object models reconstruction [3, 4], are widespread. It is generally expected that faults change only features of the control object. But, often faults change also a structure of the object. The consequences of such actions lead to the usage of the nonparametric identification methods for constructing of the object models on the base of experimental data "input/output".

The paper suggests non-parametric nonlinear dynamic models on the base of integro-power Volterra series. They contain the sequence of multidimensional weight functions $w_k(\tau_1,\ldots,\tau_k)$, $k=1,2,\ldots$ – Volterra kernels [5], which are invariant to input signal form.

Using of the models based on Volterra series allows to consider nonlinear and dynamic characteristics of the control object. With this approach, the diagnostic procedure becomes reliable and universal [6].

In this case, the diagnostic algorithm consists of the following steps:

1. Constructing the Volterra kernels on the basis of "input/output" experiment data in the frequency or time domain [7, 8].
2. Constructing the diagnostic features set (diagnostic space) on the basis of the received Volterra kernels. Classifier of control object states builds in the constructed diagnostic space using statistical recognition methods [8, 9].

The purpose of this paper is to improve the reliability and quality of diagnosis of nonlinear dynamic object state. As a source of primary data about control object, a model-based nonparametric identification in the Volterra kernels form is used [10, 11]. A set of diagnostic features of space construction is based on these models due to parameterizing the primary model as a wavelet transforms of Volterra kernels sections.

II. MODEL CONSTRUCTION IN THE FORM OF INTEGRO-POWER VOLTERRA SERIES

The considered nonlinear dynamical object can be represented by the expression (1). The input and output signals with zero initial conditions $x(t)$ can be represented by the Volterra series:

$$
\begin{aligned}
y(t) &= \int_0^t w_1(\tau)x(t-\tau)d\tau + \\
&+ \int_0^t\int_0^t w_2(\tau_1,\tau_2)x(t-\tau_1)x(t-\tau_2)d\tau_1 d\tau_2 + , \\
&+ \int_0^t\int_0^t\int_0^t w_3(\tau_1,\tau_2,\tau_3)x(t-\tau_1)x(t-\tau_2)\times \\
&\times x(t-\tau_3)d\tau_1 d\tau_2 d\tau_3 + \ldots
\end{aligned}
\tag{1}
$$

where $w_1(\tau_1)$, $w_2(\tau_1,\tau_2)$, $w_3(\tau_1,\tau_2,\tau_3)$ – Volterra kernels of the 1^{st}, 2^{nd} and 3^{rd} orders; t – current time.

High precision of Volterra kernels definition is reached with the use of antinoise methods of identification, suggested in works [5, 13].

III. DIAGNOSTIC FEATURES SPACE CONSTRUCTION

Application of the proposed integro-power model in diagnostics entails the necessity of parameterization of

Volterra kernels functions [12]: $\{w_k(t_1,t_2,\ldots,t_k)\}_{k=1,2,\ldots,N} \Rightarrow \mathbf{x}=(x_1,x_2,\ldots,x_n)'$.

Selection of the diagnostic features space has a decisive influence on the precision of the diagnostic model and, as a consequence, on the reliability of the object state classification.

A diagnostic features space usually has the following characteristics:

1. Volterra kernels samples of the 1st order $w_1(t)$, diagonal sections of Volterra kernels of the 2nd order $w_2(t,t)$ and the 3rd order $w_3(t,t,t)$ with a specified discreteness (V_k, $k=\overline{0,3}$).

2. Volterra kernels moments $\mu_r^{(k)}$ of different orders r, $r=\overline{0,3}$) ($\mathbf{M}_k$, $k=\overline{0,3}$ – Volterra kernels order).

The system of diagnostic features is based on Volterra kernel's diagonal sections samples and its moments are considered in [13].

This work proposes a universal approach to diagnostic features space construction based on coefficients of direct continuous wavelet transforms, applied to Volterra kernels of the 1st order (W_1) and to diagonal sections of Volterra kernels of the 2nd and 3rd orders **(**W_2**,** W_3**)**.

Wavelet processing provides the efficient compression of signal with slight losses of information. Therefore, it increases informativeness of diagnostic feature space.

Direct continuous wavelet transform of the function $w_n(t-T_1,t-T_2,...,t-T_{n-1},t)$ is determined by calculation of wavelet coefficients by the formula:

$$C(a,b)=\int_0^\infty w_n(t-T_1,t-T_2,...,t-T_{n-1},t)a^{-1/2}\psi(\frac{t-b}{a})dt \quad (2)$$

where $\psi(t)$ – transform function; a and b – parameters of the wavelet scaling and shifting.

IV. Quality Analysis of Constructed Diagnostic Features Space

Quality of diagnostic feature space is estimated on the base of the classification problem solving.

It is impossible to use a determinant approach to classification, because obtained models are used for all classes which form overlaying areas. In this task, the methods of object states recognition are used.

Quality of constructed feature space (informativeness) is defined on the base of the maximum of true recognition probability (TRP) criteria, applied on a subset X′ of a whole features space X (X′ ⊂ X). TRP criteria are calculated using decision rules (discriminant functions).

Due to training samples for control object of m classes, m-1 discriminant functions $d_1(\mathbf{x})$, $d_2(\mathbf{x})$, …, $d_{m-1}(\mathbf{x})$ are successively calculated. The function $d_1(\mathbf{x})$ separates the 1st class' objects from the objects of other m-1 classes; $d_2(\mathbf{x})$ – separates the 2nd class' objects from the objects of other m-2 classes; …, $d_{m-1}(\mathbf{x})$ – separates the objects of the m-1 class from the objects of m class.

The maximum value of the TRP criteria is described by the following expression:

$$TRP_{\max}=\max_k\left\{\frac{1}{m-1}\sum_{i=1}^{m-1}TRP_{ik}\right\}, \quad (3)$$

where k – serial number of diagnostic feature space X′ in full enumeration of spaces.

Thus, during the search procedure among full enumeration spaces for considered diagnostic feature space X, the most valuable combination of two, three, etc. features are determined.

V. Quality Analysis of Diagnostic Features Space Based on Wavelet Transform

Offered method of diagnostic feature space construction is analyzed on example of simulation model of nonlinear dynamic object.

A. Control object's simulation model

The simulation model of nonlinear dynamic object (Fig. 1) represents connection with feedback. Blocks of the simulation model have characteristics $W_1(t)=e^{-\alpha t}$ and $F(y)=\beta y^2(t)$.

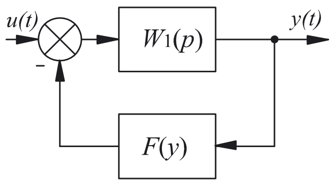

Figure 1. Simulation model of nonlinear dynamic object

The structural scheme of the Volterra model of the 3rd order is shown in Fig. 2.

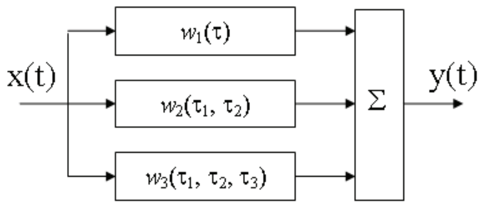

Figure 2. The structural scheme of the Volterra model of the 3rd order

The analytical expressions for Volterra kernel of the 1st order are in [13]:

$$w_1(\tau_1)=e^{-\alpha\tau_1} \quad (4)$$

Diagonal sections of Volterra kernels of the 2nd and 3rd order at $t_1 = t_2 = t_3 = t$ have the form [13]:

$$w_2(t,t)=\frac{\beta}{\alpha}(e^{-2\alpha t}-e^{-\alpha t}),$$
$$w_3(t,t,t)=2\left(\frac{\beta}{\alpha}\right)^2\cdot(e^{-3at}-2e^{-2\alpha t}+e^{-\alpha t}) \quad (5)$$

The structural scheme of the Volterra model of the 3rd order in the time domain is shown in Fig. 3.

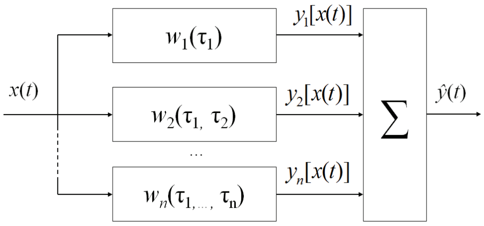

Figure 3. The structural scheme of the Volterra model of the 3rd order in the time domain

The structural scheme of the Volterra model of the 3rd order in the frequency domain is shown in Fig. 4.

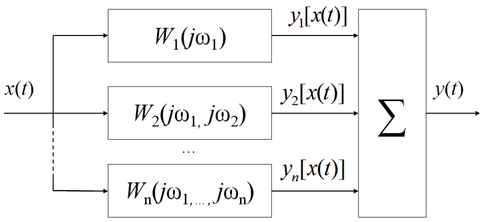

Figure 4. The structural scheme of the Volterra model of the 3rd order in the frequency domain

B. *Statement of the training and examination samples*

To diagnose the control object states Volterra kernels of the 1st order $w_1(t)$ and diagonal sections of Volterra kernels of the 2nd $w_2(t,t)$ and 3rd order $w_3(t,t,t)$ are used.

Samples of training and examination are prepared for objects of four classes (100 objects in each class). Classes are formed due to the values of parameters α and β according to the following rules:

- Normal mode – class A. This class consists of objects with parameters $\alpha \in [0.95\alpha_n,\ 1.05\alpha_n]$, $\beta \in [0.95\beta_n,\ 1.05\beta_n]$, where α_n and β_n – nominal values.
- Fault mode – class B. This class consists of objects with parameters $\alpha \in (0.9\alpha_n,\ 0.95\alpha_n) \cup (1.05\alpha_n,\ 1.1\alpha_n)$, $\beta \in [0.95\beta_n,\ 1.05\beta_n]$.
- Fault mode – class C. This class consists of objects with parameters $\alpha \in [0.95\alpha_n,\ 1.05\alpha_n]$ and $\beta \in (0.9\beta_n,\ 0.95\beta_n) \cup (1.05\beta_n,\ 1.1\beta_n)$.
- Emergency modes – class D. This class consists of objects with parameters $\alpha \in (0.9\alpha_n,\ 0.95\alpha_n) \cup (1.05\alpha_n,\ 1.1\alpha_n)$, $\beta \in (0.9\beta_n,\ 0.95\beta_n) \cup (1.05\beta_n,\ 1.1\beta_n)$.

The estimations of Volterra kernels of the 1st order $w_1(t)$ and diagonal sections of Volterra kernels of the 2nd $w_2(t,\ t)$ and 3rd order $w_3(t,\ t,\ t)$ for mentioned four classes are received as a result of simulation process.

Obtained models for all classes form overlaying areas (Fig. 5). In this case, discriminant functions are determined by the maximum probability method.

On the basis of training data sets for an object classes A, B, C and D, three discriminant functions $d_1(\mathbf{x})$, $d_2(\mathbf{x})$ and $d_3(\mathbf{x})$ are successively calculated. The function $d_1(\mathbf{x})$ separates the 1st class' A objects from the objects of the 2nd, 3rd and 4th classes B ∪ C ∪ D; $d_2(\mathbf{x})$ – separates the 2nd class' B objects from the objects of the 3rd and 4th classes C ∪ D; $d_2(\mathbf{x})$ – separates the 3rd class' C objects from the objects of 4th class D.

Further, the informativeness of different diagnostic feature spaces (discrete values of Volterra kernels, Volterra kernels moments and wavelet transform coefficients) is analyzed.

C. *Discrete values of Volterra kernels*

The training sample is created on the basis of ten discrete values of Volterra kernels of the 1st order (feature space $\mathbf{V}_1$), diagonal sections of Volterra kernels of the 2nd order (feature space $\mathbf{V}_2$) and diagonal sections of Volterra kernels of the 3rd order (feature space $\mathbf{V}_3$). Discrete values of Volterra kernels are taken with uniform step on interval $(0,\ T]$, where T – simulation time.

Diagnostic spaces are formed by full enumeration of feature combinations.

The best results of feature space selection among $\mathbf{V}_1$, $\mathbf{V}_2$ and $\mathbf{V}_3$ are shown in a tabular mode (table I).

TABLE I. VALUES OF TRP FOR FEATURE SPACES $\mathbf{V}_1$, $\mathbf{M}_1$, $\mathbf{W}_1$, $\mathbf{V}_2$, $\mathbf{M}_2$, $\mathbf{W}_2$, $\mathbf{V}_3$, $\mathbf{M}_3$, $\mathbf{W}_3$.

Features set	Informative features	TRP
$\mathbf{V}_1$	x_1, x_2, x_3, x_7	0.84
$\mathbf{M}_1$	x_1, x_2, x_3, x_4	0.83
$\mathbf{W}_1$	x_1, x_2, x_3, x_4	0.86
$\mathbf{V}_2$	x_1, x_2, x_3, x_4	0.95
$\mathbf{M}_2$	x_1, x_2, x_3, x_4	0.95
$\mathbf{W}_2$	x_1, x_2, x_3, x_4	0.96
$\mathbf{V}_3$	x_1, x_2, x_3, x_4	0.95
$\mathbf{M}_3$	x_1, x_2, x_3, x_4	0.94
$\mathbf{W}_3$	x_1, x_2, x_3, x_4	0.96

The most informative feature space for considered control object based on discrete values of Volterra kernels is the space $\mathbf{V}_2$.

The most informative parts of Volterra kernels of the 1st order and the diagonal sections of Volterra kernels of the 2nd and 3rd orders are initial areas, which correspond to the first four discrete values. For the space $\mathbf{V}_1$, $x_i = w_1(t_i)$, $i=\overline{1,4}$; for the space $\mathbf{V}_2$ – $x_i = w_2(t_i,t_i)$, $i=\overline{1,4}$; for the space $\mathbf{V}_3$ – $x_i = w_3(t_i,t_i,t_i)$, $i=\overline{1,4}$.

D. *Moments of Volterra kernels*

The training sample is created on the basis of four moments of Volterra kernels of the 1st order (feature space $\mathbf{M}_1$) and diagonal sections of Volterra kernels of the 2nd and 3rd orders (feature space $\mathbf{M}_2$, $\mathbf{M}_3$ accordingly).

The best results of feature space selection among $\mathbf{M}_1$, $\mathbf{M}_2$ and $\mathbf{M}_3$ are shown in a tabular mode (Table I).

The most informative feature space for considered control object is based on the moments of Volterra kernels of the 2nd order (the feature space $\mathbf{M}_2$).

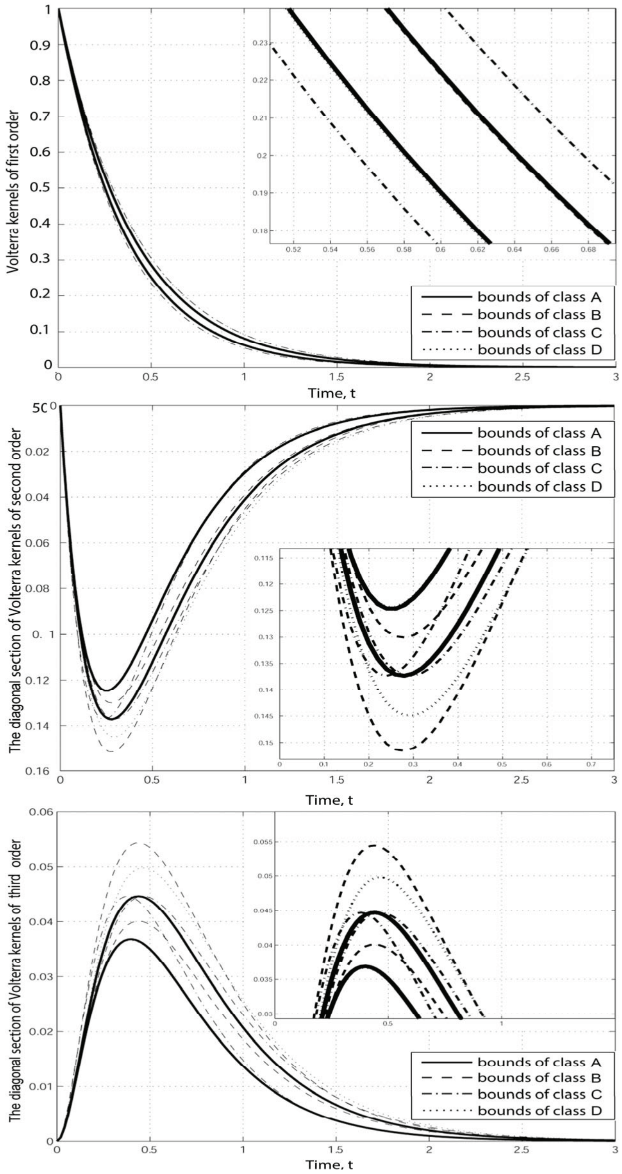

Figure 5. Volterra kernels of the 1st order $w_1(t)$ and the diagonal sections of Volterra kernels of the 2nd $w_2(t,t)$ and 3rd order $w_3(t,t,t)$ for test objects for classes A, B, C and D

The most informative moments of Volterra kernels of the 1st order and the diagonal sections of Volterra kernels of the 2nd and 3rd orders are initial areas, which correspond to the first four moments. For the space $\mathbf{M}_1$, $x_i = \mu_i^{(1)}$, $i=\overline{1,4}$; for the space $\mathbf{M}_2 - x_i = \mu_i^{(2)}$, $i=\overline{1,4}$; for the space $\mathbf{M}_3 - x_i = \mu_i^{(3)}$, $i=\overline{1,4}$.

E. Wavelet transforms of Volterra kernels

The training sample is created on the basis of the first ten coefficients of wavelet transform of Volterra kernels of the 1st order (feature space $\mathbf{W}_1$) and diagonal sections of Volterra kernels of the 2nd and 3rd orders (feature spaces $\mathbf{W}_2$, $\mathbf{W}_3$ accordingly).

The best results of features space selection among $\mathbf{W}_1$, $\mathbf{W}_2$ and $\mathbf{W}_3$ are shown in a tabular mode (Table I).

The most informative feature space for considered control object based on the wavelet transforms of Volterra kernels is the space $\mathbf{W}_2$.

The most informative part of wavelet transform of Volterra kernels of the 1st order and the diagonal sections of Volterra kernels of the 2nd and 3rd orders is the initial area, which corresponds to the first four coefficients. For the space $\mathbf{W}_1$, $x_i = C_i$, $i=\overline{1,4}$; for the space $\mathbf{W}_2 - x_i = C_i$, $i=\overline{1,4}$; for the space $\mathbf{W}_3 - x_i = C_i$, $i=\overline{1,4}$.

A comparison of the considered feature spaces quality is shown in Fig. 6.

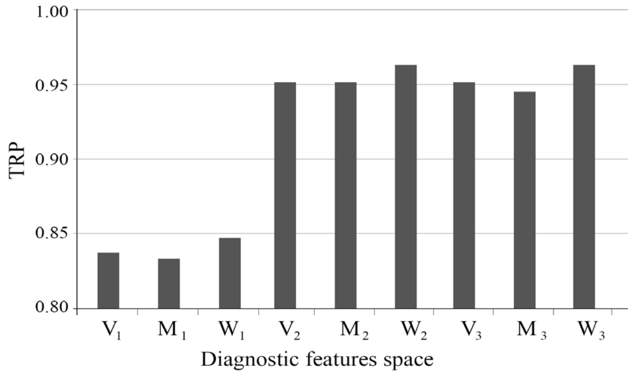

Figure 6. Values of TRP for feature spaces $\mathbf{V}_1$, $\mathbf{M}_1$, $\mathbf{W}_1$, $\mathbf{V}_2$, $\mathbf{M}_2$, $\mathbf{W}_2$, $\mathbf{V}_3$, $\mathbf{M}_3$, $\mathbf{W}_3$

VI. Robustness of Feature Space Informativeness to Estimation of Noisy Volterra Kernels

A task of analyzing robustness of informativeness feature spaces $\mathbf{V}_i$, $\mathbf{M}_i$, $\mathbf{W}_i$, $i=\overline{1,3}$ is considered. For this task training samples based on noisy Volterra kernels of the 1st order and diagonal sections of Volterra kernels of the 2nd and 3rd order are created. Volterra kernels and their diagonal sections are determined with noise rate accordingly 1%, 3%, 5%, 10% of Volterra kernels extremum. The results of robustness analysis are shown in table II and fig. 7.

TABLE II. Values of TRP for feature spaces $\mathbf{V}_1$, $\mathbf{M}_1$, $\mathbf{W}_1$, $\mathbf{V}_2$, $\mathbf{M}_2$, $\mathbf{W}_2$, $\mathbf{V}_3$, $\mathbf{M}_3$, $\mathbf{W}_3$ at different noise rates of Volterra kernels sections.

Features sets	Informative features	Noise rate, %				
		0	*1*	*3*	*5*	*10*
$\mathbf{V}_1$	x_1, x_2, x_3, x_7	0.84	0.83	0.77	0.75	0.71
$\mathbf{M}_1$	x_1, x_2, x_3, x_4	0.83	0.80	0.80	0.80	0.76
$\mathbf{W}_1$	x_1, x_2, x_3, x_4	0.86	0.84	0.83	0.82	0.81
$\mathbf{V}_2$	x_1, x_2, x_3, x_4	0.95	0.93	0.91	0.87	0.80
$\mathbf{M}_2$	x_1, x_2, x_3, x_4	0.95	0.93	0.93	0.91	0.90
$\mathbf{W}_2$	x_1, x_2, x_3, x_4	0.96	0.94	0.93	0.93	0.92
$\mathbf{V}_3$	x_1, x_2, x_3, x_4	0.95	0.92	0.90	0.85	0.79
$\mathbf{M}_3$	x_1, x_2, x_3, x_4	0.94	0.93	0.92	0.91	0.89
$\mathbf{W}_3$	x_1, x_2, x_3, x_4	0.96	0.94	0.93	0.92	0.92

According to the data given in table II the values of TRP depend on noise rate (Fig. 7). Graph clearly demonstrates the changing of diagnosis robustness with different noise rates for considered diagnostic feature spaces.

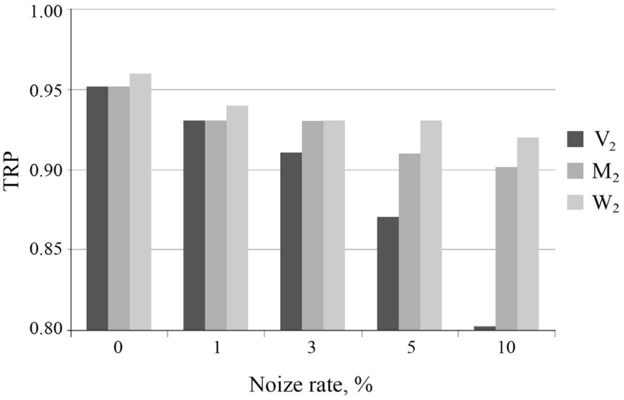

Figure 7. Informativeness of feature sets $\mathbf{V}_2$, $\mathbf{M}_2$, $\mathbf{W}_2$ under the influence of noise on Volterra kernels estimations

The most noise-robust feature spaces are received on the base of diagonal sections of Volterra kernels of the 2^{nd} and 3^{rd} orders – $\mathbf{M}_2$, $\mathbf{W}_2$. Herewith, feature space $\mathbf{W}_2$ unlike $\mathbf{M}_2$ provides robustness both at small and large noise rates.

VII. Conclusion

In this work, the universal approach to diagnostic features space construction for nonlinear dynamic objects is offered. The method is developed on the basis of the received information about control object using a model-based nonparametric identification in the form of integro–power Volterra series. Based on these models it constructs a diagnostic feature space as a set of coefficients of direct continuous wavelet transforms, applied to models in the form of Volterra kernels of the 1^{st} order and diagonal sections of Volterra kernels of the 2^{nd} and 3^{rd} orders.

Offered method of diagnostic feature space construction is analyzed on example of simulation model of nonlinear dynamic object.

The proposed method of diagnostic feature space construction provides the effective compression with small losses of information. The most informative diagnostic feature space for test control object corresponds to the first four coefficients of wavelet transform of Volterra kernels of the 2^{nd} order.

This feature space also is the most noise-robust. Unlike feature space based on moments of Volterra kernels the feature space based on wavelet transform of Volterra kernels of the 2^{nd} order s provides robustness both at small and large noise rates.

The results of numerical experiments with nonlinear dynamic object allow to make a conclusion about high perfomance of nonparametric dynamic models based on integro–power Volterra series. When the diagnostic system is constructed, the diagnostic feature space based of the Volterra kernels of the wavelet transform is the most appropriate.

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As active part of an international group, with rich experience in safety, quality and environmental protection, TÜV AUSTRIA ROMANIA is a competent partner for the economy, industry and authorities. The main features of the group – customer orientation and the ability to offer high quality services, have represented from the beginning the vision which guaranteed a successful evolution.

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Through its presence on the environmental certification market in Romania, TÜV AUSTRIA ROMANIA aims to bring added value in this field by assuring a superior quality level for the certification inspections, also offering integrated services for phyical-chemical analysis to determine contaminants and blending both legislative requirements with the requirements of producers and distributors. The RENAR certified laboratory of TÜV AUSTRIA ROMANIA is equipped with the latest generation high performance devices, operated by a team of professionals, always ready for new challenges.

Our technical assistance team is available to offer specialised support concerning standards, work practices and technologies used. In the laboratory of TÜV AUSTRIA ROMANIA physical-chemical analysis are carried out for the environment, petroleum products and food products.

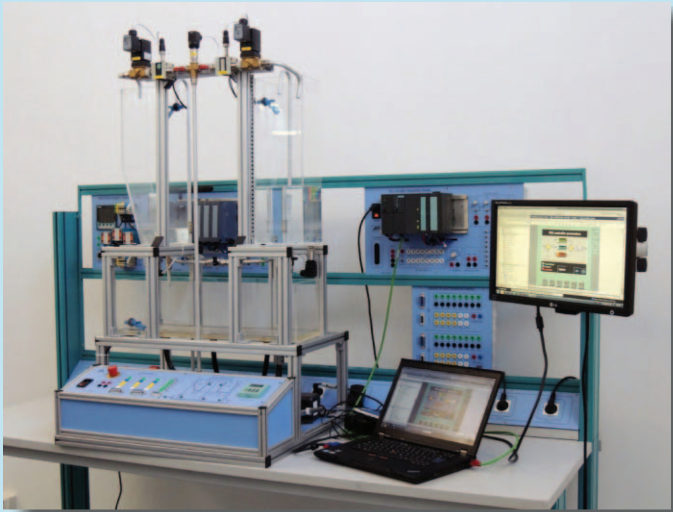
Education, experience and continuous training make TÜV AUSTRIA ROMANIA a competent partner in all aspects related to safety, quality and enviormental protection. TÜV AUSTRIA ROMANIA is at the top of the ranking in the field of research and development by attending numerous national and international committees and research relevant activities. The objectives of the TÜV AUSTRIA group are and will always be to offer technical safety, care for natural resources and achieve significant improvements in product quality.

ASTI
INDUSTRIAL AUTOMATION RESEARCH

Worlddidac Association
Quality Resources for Education

worlddidac MEMBER

Technical Training Solutions for Industrial Automation, Electrical Engineering and Robotics



ASTI Automation, company founded in 2002, has been a constant promoter of the most advanced automation systems in Romania.

Currently, the company is acting in industrial automation field, participating in projects in sectors such as: oil&gas, automotive, food industry, chemical industry, urban utilities, food&beverage, mining industry.

Since 2007, the business of the company has been extended through active involvement in increasing the quality of technical education in colleges and universities.

- The company develops didactic equipment related to approved programs of study, taking into account the current technological level encountered in main industry sectors, such as: industrial automation, electrical/electronic engineering, mechatronics, robotics.

- Training courses based on the specific requests of our customers; the courses consist of theoretical and practical applications meant for training the engineers that work in industry and also the engineering students.

- Key markets: vocational training, universities, turnkey laboratories for technical training for companies.

- Proven background of good collaboration with SIEMENS and other big companies in the industrial field.

- Strong and dynamic team of engineers and technicians, own manufacturing facilities, training center and showroom in Bucharest.

www.astiautomation.ro

Research Institute for Intelligent Computer Systems

The Research Institute for Intelligent Computer Systems (ICS) - www.ics.tneu.edu.ua is under joint supervision of Ternopil National Economic University and the Glushkov Institute of Cybernetics, National Academy of Science.

The ICS consists of the 14 research groups. During its history the ICS staff has received more than 150 invention certificates of the former USSR and 39 Ukrainian patients, they got the nine patents and applications for the invention in 2016. There were published more than 1000 papers and 131 in 2016. There were defended the 32 DSc and PhD theses, in particular, the seven in 2016.

The ICS' researchers and were awarded by 18 international grants and followed projects within the INTAS, CRDF, NSF, NATO, STCU, FP7 and bilateral programs. Since 2016 the ICS is a part of the Erasmus+ project ALIOT entitled Internet of Things: Emerging Curriculum for Industry and Human Applications together with other members of the consortium.

ICS researchers are organizing the regular International Intelligent Data Acquisition and Advanced Computing Systems (IDAACS) Workshops and Conferences since 2001 every two years under IEEE's support. In particular, the very first IDAACS Workshop was held in Foros, Crimea (2001). The last IDAACS Conference was held in Warsaw, Poland (2015).

The ICS is taking a part in the organization of International Symposium on Wireless Systems within the IDAACS Conference since 2012, the 3rd IEEE International Symposium IDAACS-SWS'2016 was held in Offenburg, Germany, 26-27 September 2016.

The ICS staff continues to keep good links with IEEE within the IEEE Student Branch at TNEU and the Instrumentation and Measurement / Computational Intelligence Joint Societies Chapter of IEEE Ukraine Section.

The International Journal of Computing is issued quarterly in the English. The four regular issues have been published in 2016. Since November 2016 the IJC Journal is indexed by Scopus Elsevier. Also, the Journal is indexed by Finnish publication forum, Norwegian Social Science Data Services, Google Scholar, and Index Copernicus International.

IEEE
UKRAINE SECTION

IEEE Ukraine Section was founded in 1991 and counts more than 400 members, consist of 13 technical chapters, 6 student branches (and Young professionals) and WIE Affinity Group. The IEEE Ukraine Section community sponsors many international conferences each year and works actively to improve a cooperation between professionals.

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