ISSN 1726-5479

SENSORS & TRANSDUCERS

10/11 vol. 133

Soft Sensors and Artificial Neural Networks

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 133, Issue 10
October 2011

www.sensorsportal.com

ISSN 1726-5479

Editors-in-Chief: professor Sergey Y. Yurish, tel.: +34 696067716, e-mail: editor@sensorsportal.com

Editors for Western Europe
Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Universitá di Brescia, Italy

Editor for Eastern Europe
Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editors for North America
Datskos, Panos G., Oak Ridge National Laboratory, USA
Fabien, J. Josse, Marquette University, USA
Katz, Evgeny, Clarkson University, USA

Editor South America
Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Africa
Maki K.Habib, American University in Cairo, Egypt

Editor for Asia
Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editor for Asia-Pacific
Mukhopadhyay, Subhas, Massey University, New Zealand

Editorial Advisory Board

Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Nothern University of Engineering, Malaysia
Annamalai, Karthigeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vygantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesh, Aladdin, De Montfort University, UK
Azamimi, Azian binti Abdullah, Universiti Malaysia Perlis, Malaysia
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Monitors Transnational, USA
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, RF Arrays Systems, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Benachaiba, Chellali, Universitaire de Bechar, Algeria
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerda Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chavali, Murthy, N.I. Center for Higher Education, (N.I. University), India
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiang, Jeffrey (Cheng-Ta), Industrial Technol. Research Institute, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad Nacional de Colombia, Colombia
Courtois, Christian, Universite de Valenciennes, France
Cusano, Andrea, University of Sannio, Italy
D'Amico, Arnaldo, Università di Tor Vergata, Italy
De Stefano, Luca, Institute for Microelectronics and Microsystem, Italy
Deshmukh, Kiran, Shri Shivaji Mahavidyalaya, Barshi, India
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dighavkar, C. G., M.G. Vidyamandir's L. V.H. College, India
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic University, China
Djordjevich, Alexandar, City University of Hong Kong, Hong Kong
Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Drljaca, Predrag, Instersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, Univ.of Ulm and KTB Mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Rosa, Juan Jose, University of Cadiz, Spain
Granel, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Haider, Mohammad R., Sonoma State University, USA
Hashsham, Syed, Michigan State University, USA
Hasni, Abdelhafid, Bechar University, Algeria
Hernandez, Alvaro, University of Alcala, Spain
Hernandez, Wilmar, Universidad Politecnica de Madrid, Spain
Homentcovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khelfaoui, Rachid, Université de Bechar, Algeria
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Kyungpook National University, Korea South

Ko, Sang Choon, Electronics. and Telecom. Research Inst., Korea South
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kockar, Hakan, Balikesir University, Turkey
Kong, Ing, RMIT University, Australia
Kratz, Henrik, Uppsala University, Sweden
Krishnamoorthy, Ganesh, University of Texas at Austin, USA
Kumar, Arun, University of South Florida, USA
Kumar, Subodh, National Physical Laboratory, India
Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Lacnjevac, Caslav, University of Belgrade, Serbia
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Lee, Jun Su, Amkor Technology, Inc. South Korea
Lei, Hua, National Starch and Chemical Company, USA
Li, Fengyuan (Thomas), Purdue University, USA
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Xian-Fang, Central South University, China
Li, Yuefa, Wayne State University, USA
Liang, Yuanchang, University of Washington, USA
Liawruangrath, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, University of Oklahoma, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, University of Vigo, Spain
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Lukaszewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Malyshev, V.V., National Research Centre 'Kurchatov Institute', Russia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
Melnyk, Ivan, Photon Control Inc., Canada
Mendes, Paulo, University of Minho, Portugal
Mennell, Julie, Northumbria University, UK
Mi, Bin, Boston Scientific Corporation, USA
Minas, Graca, University of Minho, Portugal
Moghavvemi, Mahmoud, University of Malaya, Malaysia
Mohammadi, Mohammad-Reza, University of Cambridge, UK
Molina Flores, Esteban, Benemérita Universidad Autónoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mrad, Nezih, Defence R&D, Canada
Mulla, Imtiaz Sirajuddin, National Chemical Laboratory, Pune, India
Nabok, Aleksey, Sheffield Hallam University, UK
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucine, Cherif, University of Guelma, Algeria
Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India
Pan, Jisheng, Institute of Materials Research & Engineering, Singapore
Park, Joon-Shik, Korea Electronics Technology Institute, Korea South
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politecnico de Setebal, Portugal
Petsev, Dimiter, University of New Mexico, USA
Pogacnik, Lea, University of Ljubljana, Slovenia
Post, Michael, National Research Council, Canada
Prance, Robert, University of Sussex, UK
Prasad, Ambika, Gulbarga University, India
Prateepasen, Asa, Kingmoungut's University of Technology, Thailand
Pullini, Daniele, Centro Ricerche FIAT, Italy
Pumera, Martin, National Institute for Materials Science, Japan
Radhakrishnan, S. National Chemical Laboratory, Pune, India
Rajanna, K., Indian Institute of Science, India
Ramadan, Qasem, Institute of Microelectronics, Singapore
Rao, Basuthkar, Tata Inst. of Fundamental Research, India
Raoof, Kosai, Joseph Fourier University of Grenoble, France
Rastogi Shiva, K. University of Idaho, USA
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politecnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politecnica de Cataluna, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Sapozhnikova, Ksenia, D.I.Mendeleyev Institute for Metrology, Russia
Saxena, Vibha, Bhbha Atomic Research Centre, Mumbai, India
Schneider, John K., Ultra-Scan Corporation, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Seif, Selemani, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Shah, Kriyang, La Trobe University, Australia
Silva Girao, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., NanoSonix Inc., USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Stefanescu, Dan Mihai, Romanian Measurement Society, Romania
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Inst. for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore,
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Teker, Kasif, Frostburg State University, USA
Thirunavukkarasu, I., Manipal University Karnataka, India
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tian, Gui Yun, University of Newcastle, UK
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
Vanga, Raghav Rao, Summit Technology Services, Inc., USA
Vaseashta, Ashok, Marshall University, USA
Vazquez, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyou University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Pacific Northwest National Laboratory, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung Univ. of Science and Technology, Taiwan
Wu, Zhaoyang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Lisheng, The Chinese University of Hong Kong, Hong Kong
Xu, Sen, Drexel University, USA
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Shuang-Hua, Loughborough University, UK
Yang, Wuqiang, The University of Manchester, UK
Yang, Xiaoling, University of Georgia, Athens, GA, USA
Yaping Dan, Harvard University, USA
Ymeti, Aurel, University of Twente, Netherland
Yong Zhao, Northeastern University, China
Yu, Haihu, Wuhan University of Technology, China
Yuan, Yong, Massey University, New Zealand
Yufera Garcia, Alberto, Seville University, Spain
Zakaria, Zulkarnay, University Malaysia Perlis, Malaysia
Zagnoni, Michele, University of Southampton, UK
Zamani, Cyrus, Universitat de Barcelona, Spain
Zeni, Luigi, Second University of Naples, Italy
Zhang, Minglong, Shanghai University, China
Zhang, Qintao, University of California at Berkeley, USA
Zhang, Weiping, Shanghai Jiao Tong University, China
Zhang, Wenming, Shanghai Jiao Tong University, China
Zhang, Xueji, World Precision Instruments, Inc., USA
Zhong, Haoxiang, Henan Normal University, China
Zhu, Qing, Fujifilm Dimatix, Inc., USA
Zorzano, Luis, Universidad de La Rioja, Spain
Zourob, Mohammed, University of Cambridge, UK

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA). Available in electronic and on CD. Copyright © 2011 by International Frequency Sensor Association. All rights reserved.

Sensors & Transducers Journal

Contents

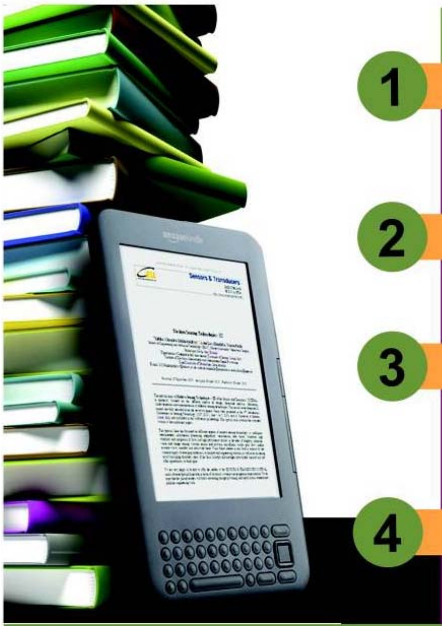
Volume 133
Issue 10
October 2011

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm



IFSA
www.sensorsportal.com

International Frequency Sensor Association Publishing

Call for Books Proposals

Sensors, MEMS, Measuring instrumentation, etc.

Benefits and rewards of being an IFSA author:

1 **Royalties**

Today IFSA offers most high royalty in the world: you will receive 50 % of each book sold in comparison with 8-11 % from other publishers, and get payment on monthly basis compared with other publishers' yearly basis.

2 **Quick Publication**

IFSA recognizes the value to our customers of timely information, so we produce your book quickly: 2 months publishing schedule compared with other publishers' 5-18-month schedule.

3 **The Best Targeted Marketing and Promotion**

As a leading online publisher in sensors related fields, IFSA and its Sensors Web Portal has a great expertise and experience to market and promote your book worldwide. An extensive marketing plan will be developed for each new book, including intensive promotions in IFSA's media: journal, magazine, newsletter and online bookstore at Sensors Web Portal.

4 **Published Format: printable pdf (Acrobat).**

When you publish with IFSA your book will never go out of print and can be delivered to customers in a few minutes.

You are invited kindly to share in the benefits of being an IFSA author and to submit your book proposal or/and a sample chapter for review by e-mail to **editor@sensorsportal.com** These proposals may include technical references, application engineering handbooks, monographs, guides and textbooks. Also edited survey books, state-of-the art or state-of-the-technology, are of interest to us. For more detail please visit: **http://www.sensorsportal.com/HTML/IFSA_Publishing.htm**

Universal Sensors and Transducers Interface (USTI)

for any sensors and transducers with frequency, period, duty-cycle, time interval, PWM, phase-shift, pulse number output

* Input frequncy range:
0.05 Hz ... 9 MHz (144 MHz)
* Selectable and constant relative error:
1 ... 0.0005 % for all frequency range
* Scalable resolution
* Non-redundant conversion time
* RS232, SPI, I2C interfaces
* Rotational speed, *rpm*
* Cx, 50 pF to 100 μF
* Rx, 10 Ω to 10 MΩ
* Pt100, Pt1000, Pt5000, Cu, Ni
* Resistive Bridges
* PDIP, TQFP, MLF packages

Just make it easy !

http://www.techassist2010.com/ info@techassist2010.com

Sensors & Transducers Journal, Vol. 133, Issue 10, October 2011, pp. 83-94

Sensors & Transducers
ISSN 1726-5479

http://www.sensorsportal.com

A Novel Method for Gearbox Fault Detection Based on Biorthogonal B-spline Wavelet

[a,b,c] Guangbin ZHANG and [b] Yunjian GE
[a] Department of Automation, University of Science & Technology of China, Hefei, 230026, China
[b] Institute of Intelligent Machines, Chinese Academy of Sciences, Hefei, 230031, China
[c] Department of Computer Engineering, Anhui University of Architecture, Hefei, 230601, China
Tel.: 086-137-21102390, fax: 086-551-3828171
E-mail: zgb@mail.ustc.edu.cn, yjge@iim.ac.cn.

Received: 30 August 2011 /Accepted: 25 October 2011 /Published: 31 October 2011

Abstract: Localized defects of gearbox tend to result in periodic impulses in the vibration signal, which contain important information for system dynamics analysis. So parameter identification of impulse provides an effective approach for gearbox fault diagnosis. Biorthogonal B-spline wavelet has the properties of compact support, high vanishing moment and symmetry, which are suitable to signal de-noising, fast calculation, and reconstruction. Thus, a novel time frequency distribution method is present for gear fault diagnosis by biorthogonal B-spline wavelet. Simulation study concerning singularity signal shows that this wavelet is effective in identifying the fault feature with coefficients map and coefficients line. Furthermore, an integrated approach consisting of wavelet decomposition, Hilbert transform and power spectrum density is used in applications. The results indicate that this method can extract the gearbox fault characteristics and diagnose the fault patterns effectively. *Copyright © 2011 IFSA.*

Keywords: Fault diagnosis, Biorthogonal B-spline wavelet, Gearbox, Coefficients line, Signal processing.

1. Introduction

Gearbox, as an important mechanism for transmitting power or rotation, is widely researched and used in automobile industry. Some mechanical defects or faults such as gear tooth wear, cracks, scoring, spalling, chipping, and pitting will result in gear tooth breakage, which may cause significant traffic accident. The occurrence of impulse response in gearbox vibration signals usually means that there exist flaws [1]. For gearbox fault diagnosis, therefore, it is very important that the study of fault diagnosis of gearbox by fault feature detection from vibration signals.

So far, different techniques have been proposed to analyze the vibration signal for fault diagnosis, such as Wigner–Ville distribution, empirical mode decomposition (EMD), matching pursuit (MP), and wavelet transform (WT) [2].

Wigner–Ville distribution has good concentration in the time-frequency plane [3]. However, even if support areas of the signal do not overlap each other, interference terms will appear to mislead the signal analysis.

EMD is an adaptive decomposition method proposed by Huang et al. which in essence extracts the intrinsic oscillation of the signal being analyzed through their characteristic time scales (i.e., local properties of the signal itself) and decomposes the signal into a number of intrinsic mode functions (IMFs), with each IMF corresponding to a specific range of frequency components contained within the signal [1, 4]. Because it still has some shortcomings when it comes to calculating instantaneous frequency or in some cases it may reveal plausible characteristics due to the mode mixing, it is untenable in effective application in impulse detection and analysis.

Matching pursuit algorithm, a greedy algorithm that chooses a waveform that is the most adapted to approximate part of the signal in each iteration, is effective in analyzing impulse response signals [5]. But, the excessive computational cost limits its engineering applications.

The wavelet transform provides powerful multi-resolution analysis in both time and frequency domain, and thereby becomes a favored tool to extract the transitory features of non-stationary vibration signals produced by the faulty gearbox. In wavelet analysis, a signal is analyzed at different scales or resolution: larger time and smaller scale window is used to look at the approximate stationary of the signal and smaller time and larger scale window at transients. Z. K. Peng summarized the application of the wavelet in machine fault diagnosis, including the fault feature extraction, the de-noising and extraction of the weak signals, and the system identification [6-7].

The wavelet analysis results in a series of wavelet coefficients, which indicate how close the signal is to the particular wavelet [8]. In order to extract the fault feature of signals more effectively, an appropriate wavelet base function should be selected.

Biorthogonal B-spline wavelet has the properties of compact support, high vanishing moments and symmetry, which are excellent properties for signal and image compression, de-noising, fast calculation, reconstruction [9-10]. By using two wavelets, one for decomposition and the other for reconstruction instead of the same single one, interesting properties are derived.

This method is based on Biorthogonal B-spline wavelet maps of coefficients by scale values and coefficients line of the time-domain vibration signal. Furthermore, to judge the fault, an integrated approach consisting of wavelet decomposition, Hilbert transform and power spectrum density is used.
The remainder of the paper is organized as follows. In Section 2, the basic theoretical background concerning biorthogonal B-spline wavelet is introduced. Section 3 gives a simulation study and analysis to verify the proposed method. Section 4 applies the method in gearbox transient feature detection by fault identification for diagnosis. Finally, conclusions are drawn in Section 5.

2. Theory of Biorthogonal B-spline Wavelet

In this section, a method of adaptive parameter identification of Morlet wavelet based on correlation filtering is presented.

2.1. Wavelet Representation and Multi-resolution Analysis

Wavelets are building blocks that can be used as the basis of function spaces, i.e. they allow the description of a function in terms simple element. Such an elemental decomposition results in an effective notation of complex data and allows an efficient numerical solution in applications. The wavelet framework has been used widely for signal analysis and image synthesis applications. Wavelets are families of functions that integrate to zero and are produced by scaling and translating a single function ψ (called mother wavelet).

$$\psi_{a,b}(x) = |a|^{-\frac{1}{2}} \psi\left(\frac{x-b}{a}\right). \tag{1}$$

For make the wavelet framework efficient computationally we disperse the scaling parameter a and translation parameter b in the following way:

$$a = 2^{-j}, \;\; b = (k/2^j)b_0, \; j,k \in Z, \tag{2}$$

where $b_0 = 1$, now we have wavelets that are of the form:

$$\psi_{j,k}(x) = 2^{j/2}\psi(2^j x - k), \quad k, j \in Z. \tag{3}$$

A multi-scale decomposition of a function f in $L^2(R)$, the space of square integrable real functions, is a linear expansion of f into a countable subset of elements $\psi_{j,k}$. Wavelets can be used to produce a multi-scale decomposition of $L^2(R)$. The idea is to decompose $L^2(R)$ into a direct sum of closed subspaces W_j, spanned by the functions $\psi_{j,k}(x)$ .A multi-resolution analysis of $L^2(R)$ consists of a sequence of nested subspaces V_j that are generated by a single function $\phi, \cdots V_{-1} \subset V_0 \subset V_1 \cdots$, whose union is dense in $L^2(R)$ and whose intersection is the null space. The function ϕ has non-zero integral and is called a scaling function. Similarly to the wavelets, ϕ originates by scaling and translation the family [11]. This collection of functions $\left\{\phi_{j,k}\right\}$ forms a basis of the approximation spaces V_j . Note that all spaces in the above sequence are scaled versions of the reference space V_0. This means that each space V_j has a natural scale 2^j . In contrast with the wavelet decomposition, in the framework of multi-resolution analysis, a function f is represented by its approximations simultaneously at all scales 2^j. Such a structure is composed of several versions of the function f that are computed by projecting f onto the spaces V_j.

2.2. Biorthogonal B-Spline Wavelets

The biorthogonal B-spline wavelet is a kind of multi-resolution representation scheme [12]. The mathematical derivation of biorthogonal B-spline wavelets is briefly introduced in the following.

Assume that $\{N_{i,j,k}(t)\}_{j=0}^{n_i}$ is the normalized B-spline basis of order k determined by vector V_i,

$$V_i = \text{span}\{N_{i,0,k}(t), N_{i,1,k}(t), \cdots N_{i,n_i,k}(t)\}, i = 0,1,\cdots. \tag{4}$$

Then they compose a nested sequence of polynomial spline spaces of degree $k-1$. On the basis of it, a MRA of the B-spline wavelets can be established. Suppose W_i be a complement space of V_i in V_{i+1}, that is

$$V_{i+1} = V_i + W_i \, . \tag{5}$$

At the same time, $\{\psi_{j,k}(t)\}_{k=1}^{m_i}$ is a basis of W_i, where

$$m_i + n_i = n_{i+1} \, . \tag{6}$$

Then $\{\psi_{j,k}(t)\}_{k=1}^{m_i}$ is a set of the B-spline wavelets. Let

$$N_{i,k} = [N_{i,0,k} \ N_{i,1,k} \cdots N_{i,n_i,k}], \psi_i = [\psi_{i,1} \ \psi_{i,2} \cdots \psi_{i,m_i}] \, . \tag{7}$$

So there exist matrices P_i of order $(n_{i+1}+1)\times(n_i+1)$ and Q_i of order $(n_{i+1}+1)\times m_i$ such that

$$[N_{i,k}\psi_i] = N_{i+1,k}\left[P_i \quad Q_i\right], \tag{8}$$

where P_i and Q_i are called the reconstruction matrices of the B-spline wavelets. Let

$$\left[A_i \ \ B_i\right]^{T'} = \left[P_i \ \ Q_i\right]^{-1}, \ \ N_{i+1,k} = [N_{i,k} \ \psi_i] \left[A_i \ \ B_i\right]^{T'}, \tag{9}$$

where matrices A_i of order $(n_i+1)\times(n_{i+1}+1)$ and B_i of order $m_i \times (n_{i+1}+1)$ are called the decomposition matrices of the B-spline wavelets.

As semiorthogonal wavelets require that wavelet space W_i is orthogonal to scale space V_i , and the orthogonality is defined by the inner product of space L^2 (R),

$$\left\langle f, g \right\rangle = \int_a^b f(t)g(t)dt \, . \tag{10}$$

In another way, those constructing biorthogonal wavelets, an essential point is to define orthogonality of W_i and V_i by discrete norm L^2 (R) for vectors, that is to define discrete inner product of space V_i as:

$$\left\langle f_i, h_i \right\rangle = d_i^T s_i \, , \tag{11}$$

where

$$f_i = N_{i,k} d_i \, , h_i = N_{i,k} s_i \, . \tag{12}$$

Then it can be known the conditions that reconstruction matrix Q_i should satisfy are column full rank and the following discrete orthogonal condition:

$$P_i^T Q_i = 0, \tag{13}$$

where 0 is the Zero-matrix of order $(n_{i+1}+1)\times m_i$. Eqs. (3), (4), (11) and (13) are the conditions that reconstruction matrices and decomposition matrices should satisfy [13].

3. Simulation Signal Test

Consider biorthogonal B-spline wavelet described in the previous section; a simulative example has been demonstrated. Results of this signal simulation studying the performance of biorthogonal B-spline wavelet are presented to realize a better understanding of this method.

For demonstrate the effects of biorthogonal B-spline wavelet, a noisy sine wave is considered, in which there are some small impulses used to simulate singularity on sine wave [14]. The time-domain original signal and signal with noise is given in Fig. 1, where the sampling time is 1.0s. Biorthogonal B-spline wavelet transform is applied to the simulative signal shown in Fig. 1, and then the values of coefficients by scale with different order of Nr and Nd are illustrated in Fig. 2. (a) and (b), respectively.

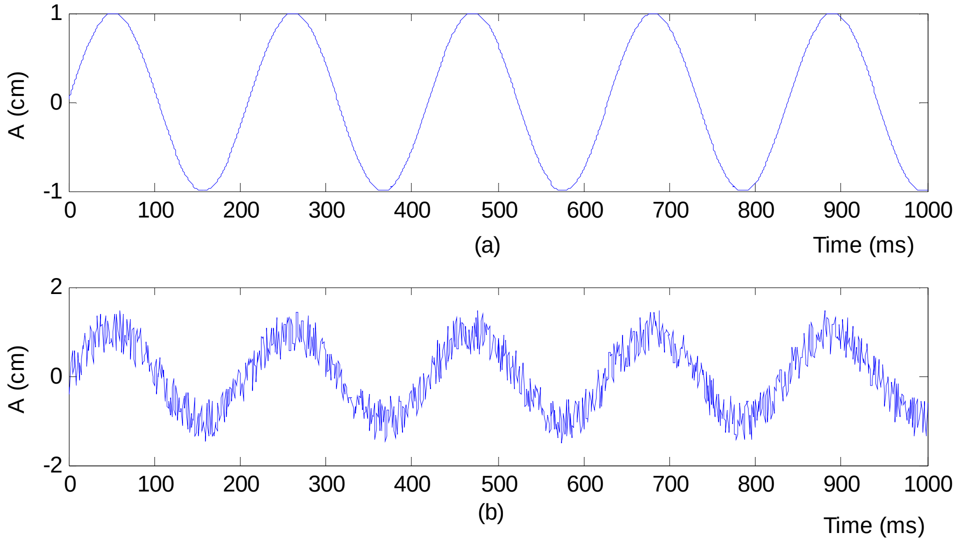
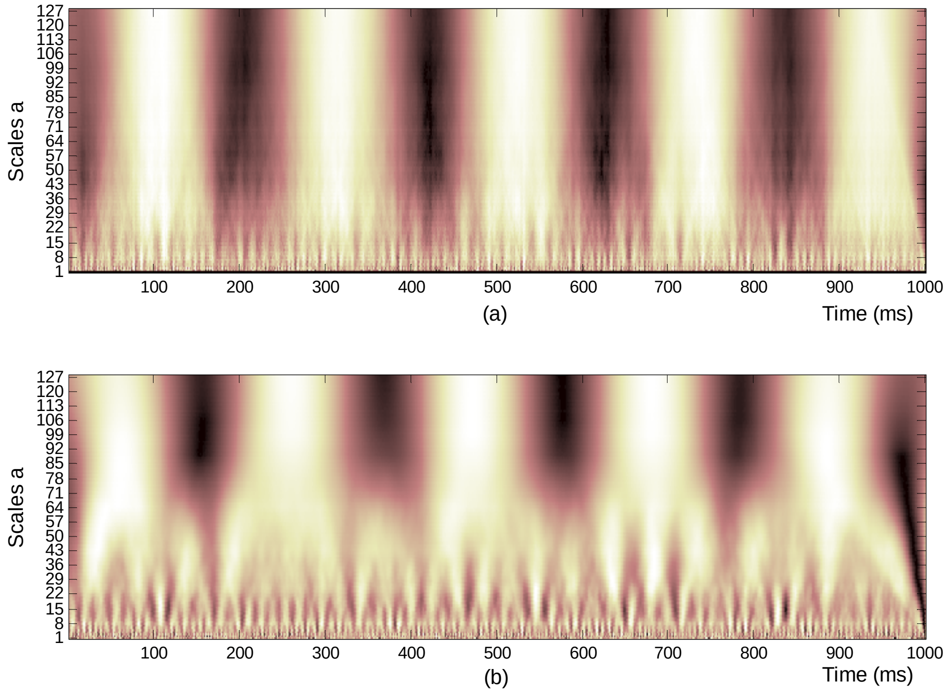


Fig. 1. (a) original signal; (b) signal with noise.

In Fig. 2, the values of coefficients map demonstrates the period of sine wave, the value of a is from 1 to 128, and the step is set 1. When the order of biorthogonal B-spline wavelet is different, like Fig. 2 (a) and Fig. 2. (b), the shape is different. But they have the same characteristic listed in follows. The white area corresponds to the positive amplitude of the simulative signal, and the black area corresponds to its negative amplitude. The high frequency components are concentrated on the map zone, in which the scale parameter a is < 22, while the low frequency components are concentrated on map zone, in which the scale parameter a is from23 to 128. At the bottom of the coefficients value map, there are five black bars, which correspond to the small impulses embedded in the sine wave. The sharp transitions from white to black in the coefficients value map correspond to jump of the wrapped phase. They exactly correspond to the inflexion points of the simulative signal. Particularly, there are distinct black bars located in the map zone, in which the scale a is from1 to 22. These black bars correspond to the small impulses embedded in the sine wave. It is obvious that the coefficients value map determines the exact positions of those small impulses and enlarge the weak information caused by the embedded small impulses. Therefore, the coefficients value map in the time scale joint representation domain reveals the precise location of the singularity as well as the scale nature of the simulative signal.



(a)

(b)

Fig. 2. By scale values of Ca,b coefficients for a =1, 2, 3, 4, 5..., (a)Nr=1,Nd=1,(b) Nr=5,Nd=5.

In other way, coefficients line is used to study the property of biorthogonal B-spline wavelet. In Fig. 3 (a), a is set 64, which is the median of scales, and in Fig. 3.(b), a is set 2. From the Fig. 3, it can be concluded that when the scale is set different values, the shapes of coefficients line have great different.. From the Fig. 3 (a), it can be found that the shape of the coefficient line is very similar with Fig. 1 (a), and the coefficients line also shows the regularity that the period of sine wave. But there is no regularity could be found from the Fig. 3 (b). .So proper scale should be selected from many procedures in biorthogonal B-spline wavelet transform. At the same time, the value of frequency that can be got is equal 0.031. Therefore, a conclusion can be drawn that the combination of the values of coefficients by scale and coefficients line can illustrate the whole and local signal characteristics and reveal signal singularity effectively [15].

4. Application in Gearbox Fault Feature Detection

To demonstrate the performance of the proposed approach, this section presents the experiment set-up and application example for the diagnosis of healthy gearbox or localized gear crack defect.

4.1. Experimental Set-up

To study the effectiveness of the presented methods for the gearbox fault feature detection, experiment is concerned with a fatigue test of an automobile transmission gearbox. Based on experimental requirement and physical modeling, the test bed system was constituted by the mainly four parts: (1) A host for monitor, (2) controlling equipments, (3) mechanism and electric equipments, (4) remote clients. Fig. 4 shows the architecture of the system with all components.

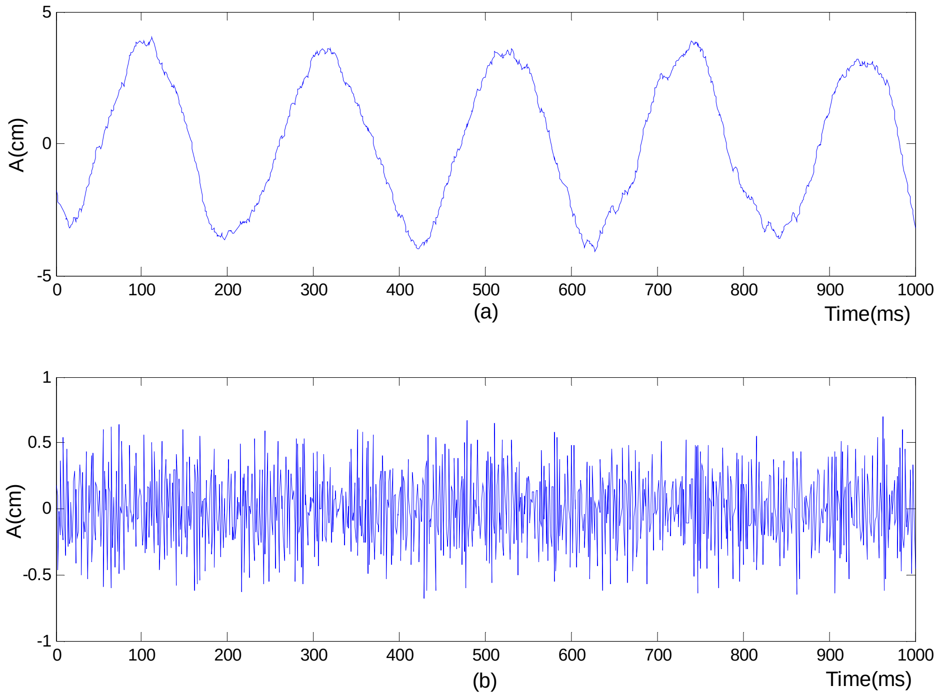


Fig. 3. (a) Coefficients line- Ca,b for scale a=64 (frequency=0.016);
(b) Coefficients line- Ca,b for scale a=2 (frequency=0.498).

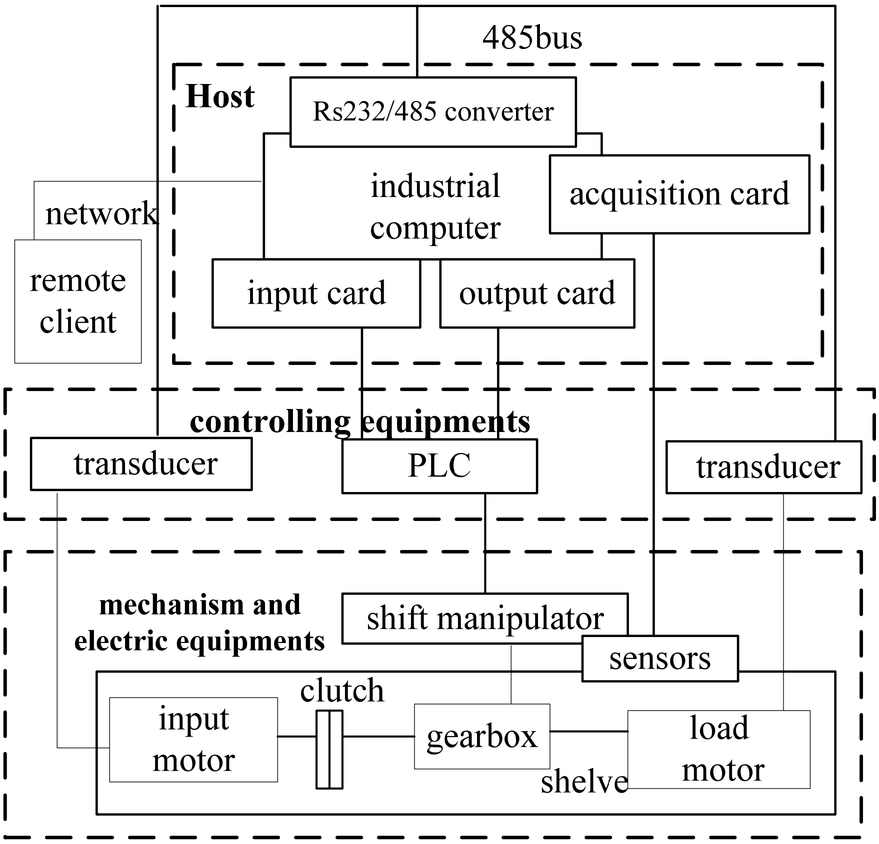


Fig. 4. Architecture of the system.

The host for monitor was an industrial computer, included digital I/O cards, simulative I/O cards and 232-485 conversion cards. It was the control core of the system. Controlling equipments consisted of PLC (programmable logic controller) and transducers for the control of shift manipulator and input or load electric facilities. Mechanism and electric equipments included the AC motors for input and load, shelves involving driving settings, clutch, automatic shift manipulator device and a series of sensors for vibration, rotate speed, pull, stress, torque and temperature. The client was any computer in the LAN (local area network) or Internet that could monitor in a long distance. There were some assistant equipment such as the control box on the spot for debugging, system cooler, the secondary meter, and the motor for gearing joint [16].

In this paper, the focus is vibration signal. Furthermore, the vibration signal was acquired by an accelerometer mounted on the outer case of the gearbox when it is loaded in the test bed. The gearbox used in experiment is LC6T46 which has six forward gears and one reverse gear. For the past experience, the sampling frequency was 20 kHz and the sampling time was varied with different gears. The input speed of the driving shaft is 1800 r/min, and the load of output motor is 220 N.m which is the half of the maximum load of LC6T46.

4.2. Case 1 Diagnosis for Healthy Gearbox

A healthy gearbox was firstly installed in the test bed and the vibration data was collected and processed. The original vibration signal for healthy gearbox is displayed in Fig. 5.

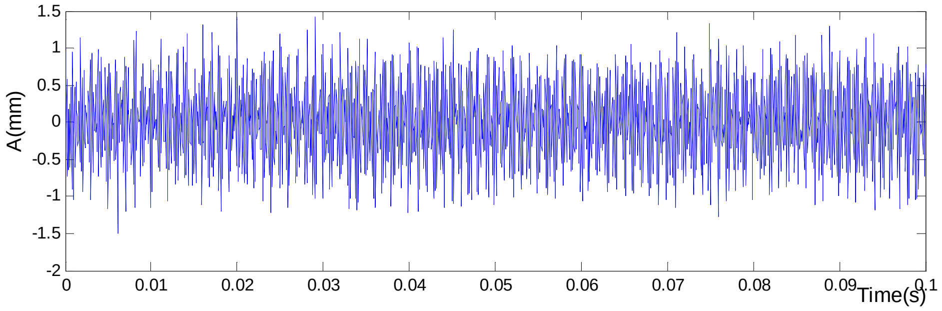
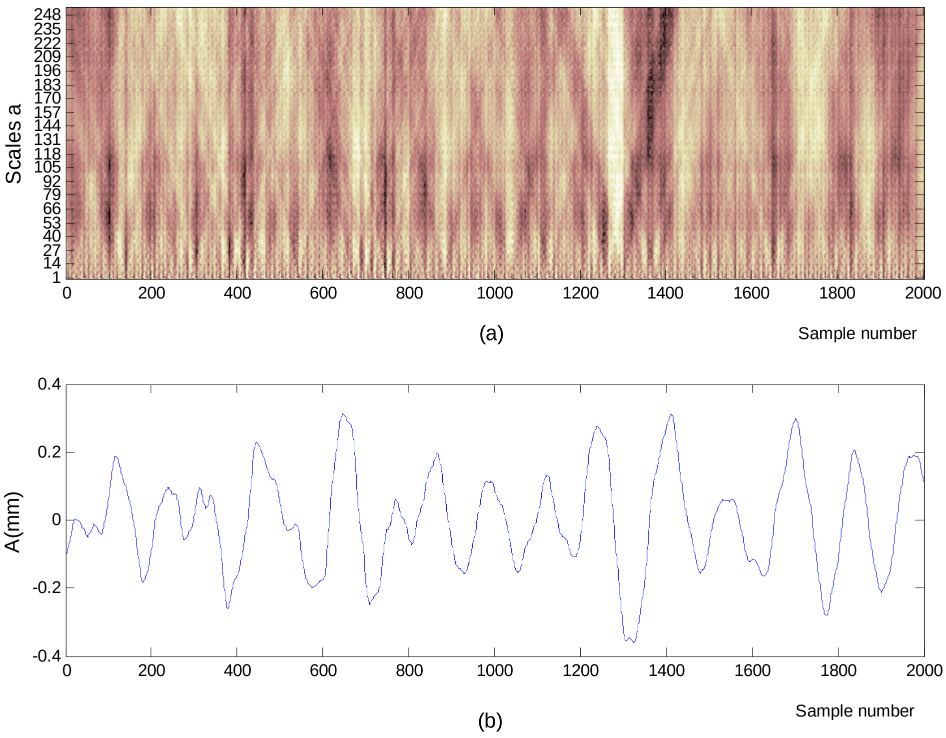


Fig. 5. Signal for healthy gearbox.

From the viewpoint of time-domain signals, it is difficult to judge the status of gearbox. Hence, the signals needed to be transformed by biorthogonal B-spline wavelet. Fig. 6 (a) is the map of values of coefficients by scale and Fig. 6 (b) is the map of coefficients line. It is clear to further observe the meaning of the map that the X-axis is indirectly proportional to time. In other words, the X-axis is sample number. The two maps both show regularity and have no singularity, so it indicates that the gearbox is a healthy gearbox.

4.3. Case 2 Diagnoses for Fault Feature Identification

To prove the efficiency of the proposed method, the typical vibration signal caused by one driving gear teeth broken is shown in Fig. 7. The time domain signal fails to demonstrate the characteristic feature of the gearbox vibration signal. Fig. 8 (a) is the map of values of coefficients by scale and Fig. 8 (b) is the map of coefficients line. Fig. 8 expresses the singularity feature of the gearbox vibration signal, but from which it can not be seen that the specific reasons leading to fault. Furthermore it is difficult to spot the time or frequency of fault, hence, the proposed method is robust even when applied to non-stationary signals. So, the decomposition with biorthogonal B-spline wavelet is used to analyze the fault signal.



(a)

(b)

Fig. 6. (a) By scale values of Ca,b coefficients for a =1, 2, 3, 4, 5...,
(b) Coefficients line- Ca,b for scale a=128 (frequency=0.005), Nr=5,Nd=5.

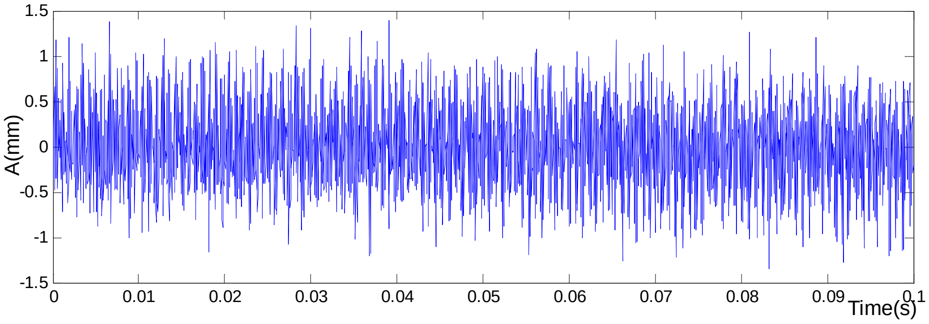


Fig. 7. Signal for gearbox with localized crack.

The fourth level of decomposition with Biorthogonal B-spline wavelet is used to transform the default signal [17]. The result of decomposition is shown in Fig. 9, d1-d4, respectively, of which the first, second, third and four level detail signals. the X-axis is sample number and the Y-axis represents the relative amplitude of the signal.

In order to further determine the cause of the failure, Hilbert transform of the first level detail signal is used to envelope analysis [18]. From the Fig. 10 (b), power spectrum density (PSD) of d1, it is obviously found the existence of frequency of 1455 Hz. By querying the gearbox fault characteristic frequency table, it is known that the bearing outer ring faulty has occurred. At the same time, the existence of frequency of 810 Hz shows pitting corrosion failure of gear. As a comparison, in

Fig. 10 (a), the PSD of raw signals, it is only fount that the mesh frequency.

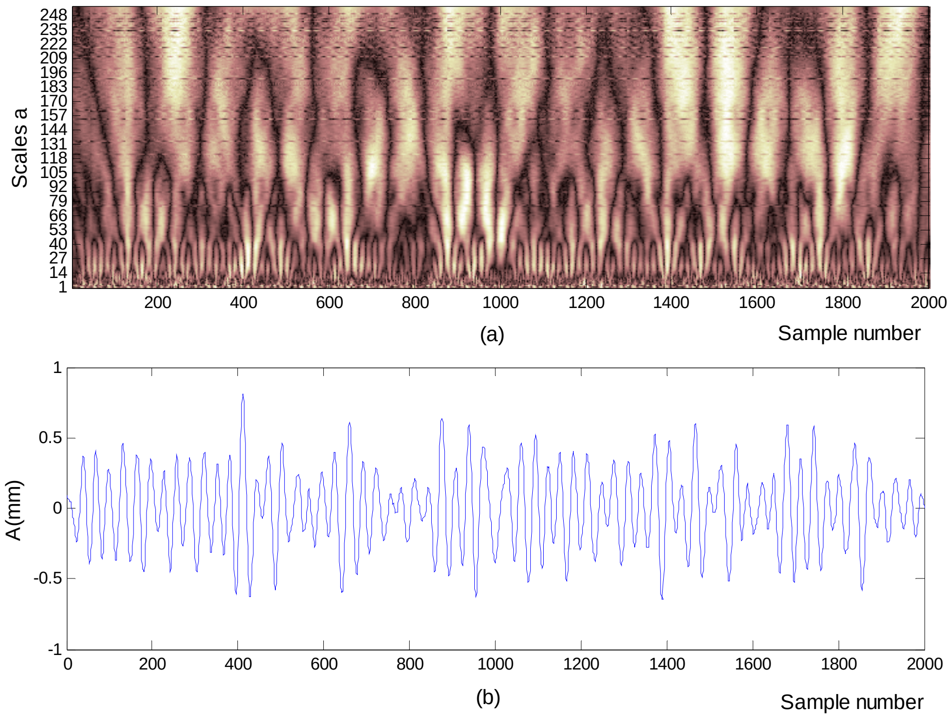


Fig. 8. (a) By scale values of Ca,b coefficients for a =1, 2, 3, 4, 5...,
(b) Coefficients line- Ca,b for scale a=128 (frequency=0.005), Nr=5,Nd=5.

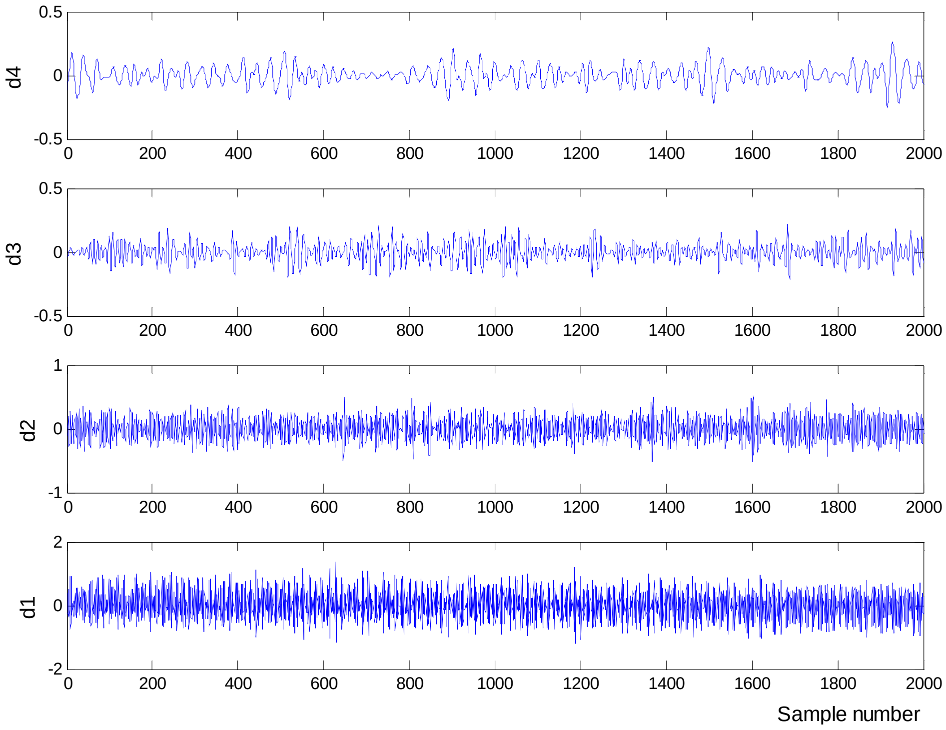


Fig. 9. Wavelet decomposition detail signal.

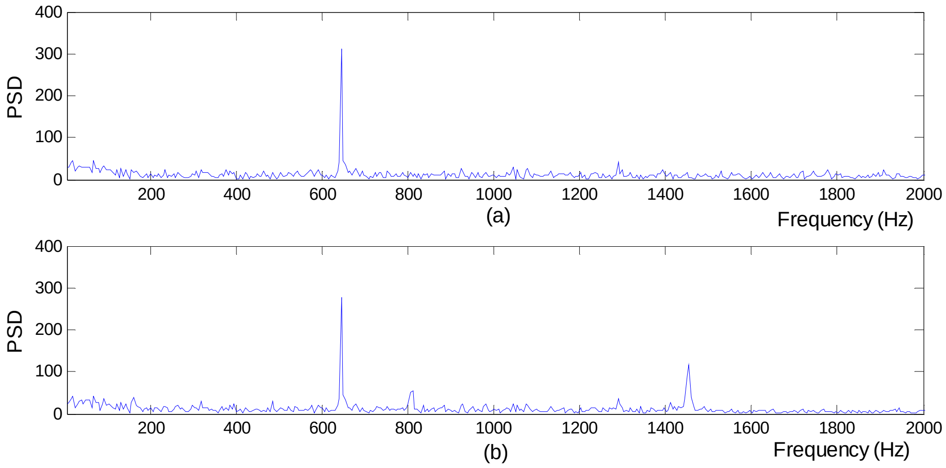


Fig. 10. (a) PSD of raw vibration signals; (b) PSD of first level detail signal.

5. Conclusions

Biorthogonal B-spline wavelet method proposed represents an attempt in the direction of parameter identification and feature detection for fault diagnosis. This wavelet exhibits the properties of compact support, high vanishing moments and symmetry, which are nice properties for signal and image compression, de-noising, fast calculation, reconstruction.

The simulation study demonstrates that the proposed method is effective in identifying parameters of singularity. Practical vibration signal monitored from a gearbox with localized gear crack fault is analyzed by the presented method. According to the coefficients maps and PSD of decomposition detail signal, the characteristic of localized gear defect can be easily recognized.

In conclusion, the other gearbox applications have not yet been provided in the paper; however, it conforms that the method has the potential applicability for monitoring gearbox and other rotating mechanical components such as transmission shafts and engines. Further research on the different mother wavelet function could be conducted to optimize for specific purposes.

Acknowledgments

This research is supported partly by the Natural Science Foundation of China (no. 60910005) and the Natural Science Foundation of Anhui Province of China (no. KJ2011A059).

References

[1]. W. Bartelmus, R. Zimroz, Vibration condition monitoring of planetary gearbox under varying external load, *Mechanical Systems and Signal Processing*, Vol. 23, No. 1, 2009, pp. 246-257.

[2]. Q. Gao, C. Duan, H. Fan, et al., Rotating machine fault diagnosis using empirical mode decomposition, *Mechanical Systems and Signal Processing*, Vol. 22, No. 5, 2008, pp. 1072-1081.

[3]. E. G. Strangas, S. Aviyente, S. H. Zaidi, Time–frequency analysis for efficient fault diagnosis and failure prognosis for interior permanent-magnet AC motors, *IEEE Transactions on Industrial Electronics*, Vol. 55, No. 12, 2008, pp. 4191-4199.

[4]. Y. Lei, Z. He, Y. Zi, Application of the EEMD method to rotor fault diagnosis of rotating machinery, *Mechanical Systems and Signal Processing*, Vol. 23, No. 4, 2009, pp. 1327-1338.

[5]. Shibin Wang, Z. K. Zhu, Adaptive parameter identification based on Morlet wavelet and application in

gearbox fault feature detection, *EURASIP Journal on Advances in Signal Processing*, Vol. 2010, 2010, pp. 842-879.

[6]. Y. Wang, Z. He, Enhancement of signal de-noising and multiple fault signatures detecting in rotating machinery using dual-tree complex wavelet transform, *Mechanical Systems and Signal Processing*, Vol. 24, No. 1, 2010, pp. 119-137.

[7]. Z. K. Peng, F. L. Chu, Application of the wavelet transform in machine condition monitoring and fault diagnostics, *Mechanical Systems and Signal Processing*, Vol. 18, No. 2, 2004, pp. 199-221.

[8]. Hui Li, Yuping Zhang, Haiqi Zheng, Application of Hermitian wavelet to crack fault detection in gearbox, *Mechanical Systems and Signal Processing*, Vol. 25, 2011, pp. 1353-1363.

[9]. Huawei Wang, Kai Tang, Kaihuai Qin, Biorthogonal wavelets based on gradual subdivision of quadrilateral meshes, *Computer Aided Geometric Design*, Vol. 25, 2008, pp. 816-836.

[10]. Chen Liping; Kong Xiangzeng; Weng Bin, A novel robust mesh watermarking based on BNBW, *EURASIP Journal on Advances in Signal Processing*, Vol. 2011, 2011, pp. 216-225.

[11]. S. J. Xiao, X. Q. Jiang, L. Blunt, Comparison study of the biorthogonal spline wavelet filtering for areal rough surfaces, *International Journal of Machine Tools & Manufacture*, Vol. 41, 2001, pp. 103-121.

[12]. Rijing Pan, Zhiqiang Yao, Biorthogonal nonuniform B-spline wavelets based on a discrete norm, *Computer Aided Geometric Design*, Vol. 26, 2009, pp. 480-492.

[13]. Tian-Xiao He, Biorthogonal spline type wavelets, *Computers and Mathematics with Applications*, Vol. 2004, No. 1, 2004, pp. 22-38.

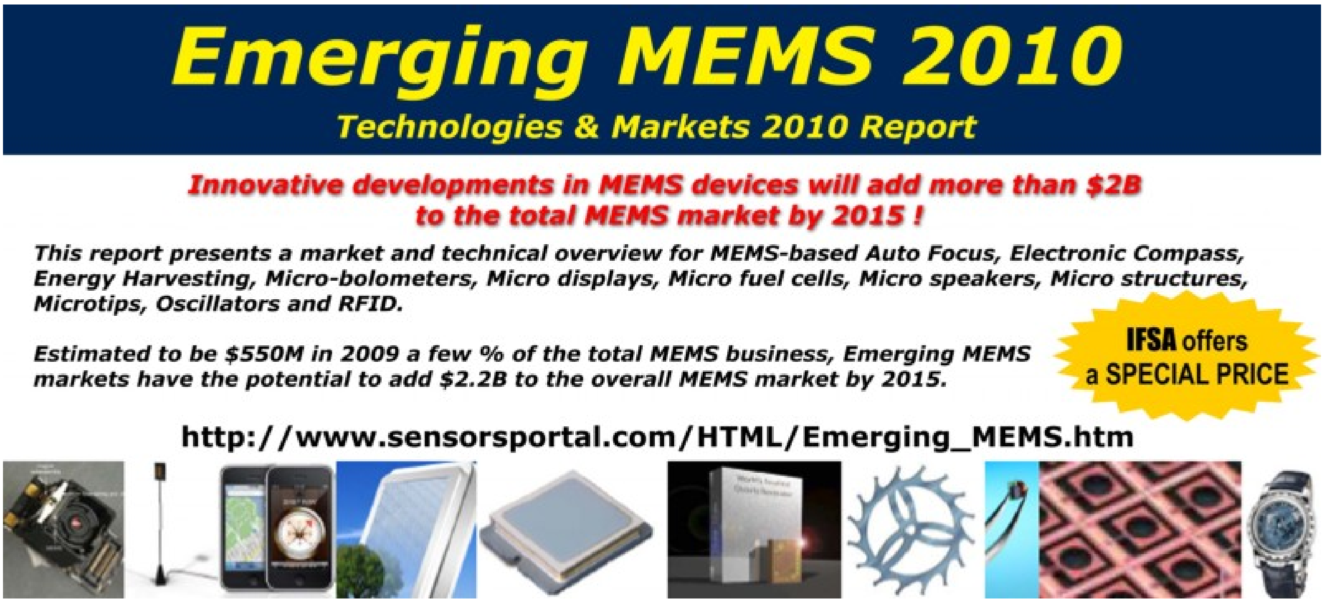
[14]. H. B. Dong, X. F. Chen, B. Li, et al., Rotor crack detection based on high-precision modal parameter identification method and wavelet finite element model, *Mechanical Systems and Signal Processing*, Vol. 23, No. 3, 2009, pp. 869-883.

[15]. H. X. Chen, S. K. Patrick, G. Chua, et al., Vibration analysis with lifting scheme and generalized cross validation in fault diagnosis of water hydraulic system, *Journal of Sound and Vibration*, Vol. 301, No. 3, 2007, pp. 458-480.

[16]. G. Kerschen, F. Poncelet, J. C. Golinval, Physical interpretation of independent component analysis in structural dynamics, *Mechanical Systems and Signal Processing*, Vol. 21, No. 4, 2007, pp. 1561-1575.

[17]. M. A. Jafarizadeh, R. Hassannejad, M. M. Ettefagh, et al., Asynchronous input gear damage diagnosis using time averaging and wavelet filtering, *Mechanical Systems and Signal Processing*, Vol. 22, No. 1, 2008, pp. 172-201.

[18]. V. K. Rai, A. R. Mohanty, Bearing fault diagnosis using FFT of intrinsic mode functions in Hilbert–Huang transform, *Mechanical Systems and Signal Processing*, Vol. 21, No. 6, 2007, pp. 2607-2615.



The 3rd International Conference on Sensor Device Technologies and Applications

SENSORDEVICES 2012

19 - 24 August 2012 - Rome, Italy

Deadline for papers: 5 April 2012

Tracks: Sensor devices - Ultrasonic and Piezosensors - Photonics - Infrared - Geosensors - Sensor device technologies - Sensors signal conditioning and interfacing circuits - Medical devices and sensors applications - Sensors domain-oriented devices, technologies, and applications - Sensor-based localization and tracking technologies

http://www.iaria.org/conferences2012/SENSORDEVICES12.html

The 6th International Conference on Sensor Technologies and Applications

SENSORCOMM 2012

19 - 24 August 2012 - Rome, Italy

Deadline for papers: 5 April 2012

Tracks: Architectures, protocols and algorithms of sensor networks - Energy, management and control of sensor networks - Resource allocation, services, QoS and fault tolerance in sensor networks - Performance, simulation and modelling of sensor networks - Security and monitoring of sensor networks - Sensor circuits and sensor devices - Radio issues in wireless sensor networks - Software, applications and programming of sensor networks - Data allocation and information in sensor networks - Deployments and implementations of sensor networks - Under water sensors and systems - Energy optimization in wireless sensor networks

http://www.iaria.org/conferences2012/SENSORCOMM12.html

The 5th International Conference on Advances in Circuits, Electronics and Micro-electronics

CENICS 2012

19 - 24 August 2012 - Rome, Italy

Deadline for papers: 5 April 2012

Tracks: Semiconductors and applications - Design, models and languages - Signal processing circuits - Arithmetic computational circuits - Microelectronics - Electronics technologies - Special circuits - Consumer electronics - Application-oriented electronics

http://www.iaria.org/conferences2012/CENICS12.html

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

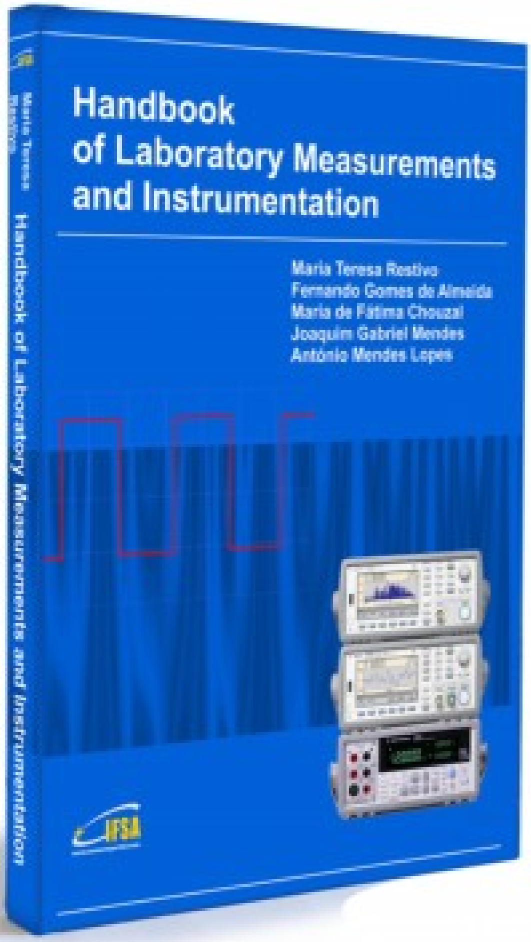
- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2011.pdf


Handbook of Laboratory Measurements and Instrumentation
Maria Teresa Restivo
Fernando Gomes de Almeida
Maria de Fátima Chouzal
Joaquim Gabriel Mendes
António Mendes Lopes
IFSA