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Introduction

This proceeding contains papers which were presented in Conference on Industrial and Applied Mathematics. The editors would like to express their deepest gratitude to all presenters, contributors/authors and participants of this conference for their overwhelming supports that turn this conference into a big success. While every single effort has been made to ensure consistency of format and layout of the proceedings, the editors assume no responsibility for spelling, grammatical and factual errors. Besides, all opinions expressed in these papers are those of the authors and not of the conference Organizing Committee nor the editors.

The Conference on Industrial and Applied Mathematics is the first international conference held at Institut Teknologi Bandung-Indonesia, during July 6 - 8, 2010; hosted by Industrial and Financial Mathematics Research Division, Faculty of Mathematics and Natural Sciences ITB. The research division has continuing research interests in financial mathematics, optimization, applied probability, control theory and its application; biological, physical modeling and the application of mathematics in sciences, fluid dynamics, and numerical methods and scientific computing. The conference provided a venue to exchange ideas in those areas and any aspect of applied mathematics, in promoting both established and new relationships.

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Table of Content

		Page
The committees of the conference		i
Introduction		ii
Table of Content		iii
Research Articles:		
1	An adaptive nonstationary control method and its application to positioning control problems, <i>Susumu Hara</i>	1-8
2	Some aspects of modelling pollution transport in groundwater aquifers, <i>Robert McKibbin</i>	9-16
3	Jets and Bubbles in Fluids – Fluid Flows with Unstable Interfaces, Larry K. Forbes	17-25
4	Boundary Control of Hyperbolic Processes with Applications in Water Flow, <i>M. Herty and S. Veelken</i>	26-28
5	Isogeometric methods for shape modeling and numerical simulation, Bernard Mourrain, Gang Xu	29-33
6	FOURTH-ORDER QSMSOR ITERATIVE METHOD FOR THE SOLUTION OF ONE-DIMENSIONAL PARABOLIC PDE'S, J. Sulaiman, M.K. Hasan, M. Othman, and S. A. Abdul Karim	34-39
7	A Parallel Accelerated Over-Relaxation Quarter-Sweep Point Iterative Algorithm for Solving the Poisson Equation, Mohamed Othman, Shukhrat I. Rakhimov, Mohamed Suleiman and Jumat Sulaiman	40-43
8	Value-at-Risk (VaR) using ARMA(1,1)-GARCH(1,1), Sufianti and Ukur A. Sembiring	44-49
9	Decline Curve Analysis in a Multiwell Reservoir System using State-Space Model, <i>S. Wahyuningsih</i> ⁽¹⁾ , <i>S. Darwis</i> ⁽²⁾ , <i>A.Y. Gunawan</i> ⁽³⁾ , <i>A.K. Permadi</i>	50-53
10	Study of Role of Interferon-Alpha in Immunotherapy through Mathematical Modelling, <i>Mustafa Mamat, Edwin Setiawan Nugraha, Agus</i> <i>Kartono , W M Amir W Ahmad</i>	54-62
11	Improving the performance of the Helmbold universal portfolio with an unbounded learning parameter, Choon Peng Tan and Wei Xiang Lim	63-66
12	Optimal Design The Interval Type-2 Fuzzy PI+PD Controller And	67-71

Superconducting Energy Magnetic Storage (SMES) For Load Frequency Control Optimization On Two Area Power System, *Muh Budi R Widodo, M Agus Pangestu H.W*

- 13 Dependence of biodegradability of xenobiotic polymers on population of 72-78 microorganism, Masaji Watanabe and Fusako Kawai
- 14 **PROTOTYPE OF VISITOR DISTRIBUTION DETECTOR FOR COMMERCIAL** 79-85 **BUILDING,** Sukarman, Suharyanto, Samiadji Herdjunanto
- 15 **APPLICATION ANFIS FOR NOISE CANCELLATION,** *Sukarman* 86-93
- 16 THE STABILITY OF THE MECD SCHEME FOR LARGE SYSTEM OF ORDINARY 94-99 DIFFERENTIAL EQUATIONS, Supriyono
- 17 Real Time Performance of Fuzzy PI+Fuzzy PD Self Tuning Regulator In 100-103 Cascade Control, Mahardhika Pratama, Syamsul Rajab, Imam Arifin, Moch.Rameli
- 18 APPROXIMATION OF RUIN PROBABILITY FOR INVESTMENT WITH 104-108 INDEPENDENT AND IDENTICALLY DISTRIBUTED RANDOM NET RETURNS AND MULTIVARIATE NORMAL MEAN VARIANCE MIXTURE DISTRIBUTED FORCES OF INTEREST IN FIXED PERIOD, Ryan Kurniawan and Ukur Arianto Sembiring
- 19 **Stochastic History Matching for Composite Reservoir,** *Sutawanir Darwis,* 109-115 Agus Yodi Gunawa, Sri Wahyuningsih, Nurtiti Sunusi, Aceng Komarudin Mutaqin, Nina Fitriyani
- 20 **PROBABILITY ANALYSIS OF RAINY EVENT WITH THE WEIBULL** 116-120 **DISTRIBUTION AS A BASIC MANAGEMENT IN OIL PALM PLANTATION,** *Divo D. Silalahi*
- 21 A Multi-Scale Approach to the Flow Optimization of Systems Governed by 121-126 the Euler Equations, Jean Medard T. Ngnotchouye, Michael Herty, and Mapundi K. Banda
- 22 Modelling and Simulating Multiphase Drift-flux Flows in a Networked 127-133 Domain, Mapundi K. Banda, Michael Herty, and Jean Medard T. Ngnotchouye
- 23 **Calculating Area of Earth's Surface Based on Discrete GPS Data,** *Alexander A* 134-137 *S Gunawan , Aripin Iskandar*
- 24 Study on Application of Machine Vision using Least-Mean-Square (LMS), 138-144 Hendro Nurhadi and Irhamah
- 25 **Cooperative Linear Quadratic Game for Descriptor System**, *Salmah* 145-250

- 26 ARMA Model Identification using Genetic Algorithm (An Application to Arc 151-155 Tube Low Power Demand Data), Irhamah, Dedy Dwi Prastyo and M. Nasrul Rohman
- 27 A Particle Swarm Optimization for Employee Placement Problems in the 156-161 Competency Based Human Resource Management System, Joko Siswanto and The Jin Ai
- 28 Measuring Similarity between Wavelet Function and Transient in a Signal 162-166 with Symmetric Distance Coefficient, Nemuel Daniel Pah
- 29 An Implementation of Investment Analysis using Fuzzy Mathematics, 167-169 Novriana Sumarti and Qino Danny
- 30 Simulation of Susceptible Areas to the Impact of Storm Tide Flooding 170-178 along Northern Coasts of Java, Nining Sari Ningsih, Safwan Hadi, Dwi F. Saputri, Farrah Hanifah, and Amanda P.Rudiawan
- 31 **Fuzzy Finite Difference on Calculation of an Individual' Bank Deposits,** 179-183 Novriana Sumarti and Siti Mardiah
- 32 An Implementation of Fuzzy Linear System in Economics, Novriana Sumarti 184-187 and Cucu Sukaenah
- 33 Compact Finite Difference Method for Solving Discrete Boltzmann 188-193 Equation, PRANOWO, A. GATOT BINTORO
- 34 Natural convection heat transfer with an Al₂O₃ nanofluids at low Rayleigh 194-199 number, Zailan Siri, Ishak Hashim and Rozaini Roslan
- 35 Optimization model for estimating productivity growth in Malaysian food 200-206 manufacturing industry, *Nordin Hj. Mohamad, and Fatimah Said*
- 36 Numerical study of natural convection in a porous cavity with transverse 207-211 magnetic field and non-uniform internal heating, *Habibis Saleh*, *Ishak Hashim and Rozaini Roslan*
- 37 THE DISTRIBUTION PATTERN AND ABUNDANCE OF ASTEROID AND 212-215 ECHINOID AT RINGGUNG WATERS SOUTH LAMPUNG, Arwinsyah Arka, Agus Purwoko, Oktavia
- 38 Low biomass of macrobenthic fauna at a tropical mudflat: an effect of 216-224 latitude?, Agus Purwoko and Wim J. Wolff
- 39 Density and biomass of the macrobenthic fauna of the intertidal area in 225-234 Sembilang national park, South Sumatra, Indonesia, Agus Purwoko and Wim J. Wolff

- 40 Intelligent traffic light system for AMJ highway, Nur Ilyana Anwar Apandi, 235-238 Puteri Nurul Fareha M. Ahmad Mokhtar, Nur Hazahsha Shamsudin and Anis Niza Ramani and Mohd Safirin Karis
- 41 Goodness of Fit Test for Gumbel Distribution Based on Kullback-Leibler 239-245 Information using Several Different Estimators, S. A. Al-Subh, K. Ibrahim, M. T. Alodat, A. A. Jemain
- 42 Impact of shrimp pond development on biomass of intertidal 246-256 macrobenthic fauna: a case study at Sembilang, South Sumatra, Indonesia, Agus Purwoko, Arwinsyah Arka and Wim J. Wolff

Measuring Similarity between Wavelet Function and Transient in a Signal with Symmetric Distance Coefficient

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ABSTRACT

Wavelet transform has been developed and applied in various areas of science and engineering. It offers better signal processing capabilities due to the existence of a large number of wavelet functions. The superiority comes with a requirement of methods to select a proper wavelet function for each signal or application. Selection methods based on signal properties are not always applicable due to the lack of mathematical definition of most analyzed signals. Wavelet function can be selected based on its shape similarity to interested transient in input signal. The selection method is subjective since there is no quantified parameter to measure this similarity. This paper introduces a new parameter, symmetric distance coefficient (SDC) to measure similarity between wavelet function and transient in a signal. It is based on a fact that wavelet coefficients of a transient that has similar shape and similar time support to a wavelet function are always symmetric. The parameter measures similarity by measuring the degree of symmetry in wavelet coefficients. The paper also reports an experiment to demonstrate procedures to measure this similarity using SDC.

KEYWORDS

Wavelet; symmetric; transient; transformation.

I.INTRODUCTION

Wavelet Transform (WT) is a recent development in signal processing [1, 2]. Wavelet transform of a signal $f \in L^2(R)$ is defined as a correlation between the signal and a dilated-shifted wavelet function $\psi_{s,\sigma}$.

$$Wf(s,\sigma) = \langle f, \psi_{s,\sigma}^* \rangle = \int_{-\infty}^{+\infty} f(t) \frac{1}{\sqrt{s}} \psi^*(\frac{t-\sigma}{s}) dt$$
(1)

The magnitude of wavelet coefficient, $/Wf(s, \sigma)/$, indicates how well they correlate around $t = \sigma$, and is determined by the matching between the

properties of wavelet function and the properties of the analyzed signal. WT offers a large option of wavelet functions. This flexibility comes with a need of methods to select wavelet function.

Common wavelet selection methods were based on the matching between the properties of wavelet function and the properties of the analyzed signal [1-8]. The methods require both, the wavelet function and the analyzed signal, to be defined mathematically. All wavelet functions are defined mathematically, but, most analyzed signals are natural signals with lack of mathematical expression. Other wavelet function selection method was based on visual shape similarity between interested transient in input signal and wavelet function [9-14]. The method, was not accurate since the similarity was only judged by visual inspection.

This paper introduces a new parameter to measure similarity between wavelet function and transient in a signal by measuring the degree of symmetry in wavelet coefficients. The new parameter is called 'symmetric distance coefficient' (SDC) [15]. This paper is organized into five sections. Following this introduction, Section II elaborates the issue of measuring shape similarity. Section III definition of SDC, while Section IV presents the procedure and experimets to measure shape similarity between a wavelet function and transients in a signal. Finally, Section V gives the concluding remark.

II. MEASURING SHAPE SIMILARITY

Shape similarity between a wavelet function and a transient in a signal can be observed on the symmetric pattern in wavelet coefficients in the neighborhood of the center of the transient, $t = t_c$ [16]. It is based on the fact that correlation

function of two similar shape functions is always symmetric (even-symmetric). Consequently, if a wavelet function has similar shape to a transient at $t = t_c$, the wavelet coefficients in the neighborhood of $\sigma = t_c$ are even-symmetric. This symmetry feature is not altered by signal amplification.

There is a difficulty in using the symmetric nature to measure shape similarity because in the real world, it is nearly impossible to find a wavelet function that has exactly a similar shape to any transients in input signal. One can only find a wavelet function that is almost similar. This condition will produce nearly evensymmetric wavelet coefficients. To measure this 'nearly similar' condition, it is necessary to have a parameter to measure symmetry in gradual levels. Unfortunately, symmetry is only defined as a discrete parameter (i.e. symmetry or asymmetry). The new parameter, introduced in this paper, was developed to measure symmetry in gradual levels. The parameter is applied to the case of wavelet function selection.

III. SYMMETRIC DISTANCE COEFFICIENT

A function, f(t), is considered symmetric around $t = t_c$ if

$$\left\{f(t_c + \tau) = \pm f(t_c - \tau)\right\}_{\tau \in [-t_s, t_s]}$$
(2)

where τ is any value in a time support of $[-t_s, t_s]$. Equation (2) strictly distinguishes between symmetric and asymmetric function. SDC measures the degree of symmetry in gradual levels. It is inspired by the concept of symmetric distance in image analysis that measures the minimum effort required to modify pattern in an image into its symmetric shape [17-19].

SDC is the ratio between the energy of the difference between left and right side of a function around its center $t = t_c$, and the energy of the function within the same time support of $t = [t_c - t_s, t_c + t_s]$. It is illustrated in Fig. 1.

$$SDC(t_{c}, t_{s}) = \frac{\int_{0}^{t_{s}} (f(t_{c} - \tau) - f(t_{c} + \tau))^{2} d\tau}{\int_{-t_{s}}^{t_{s}} f^{2}(t_{c} - \tau) d\tau}$$
(3)



Figure 1. A nearly even-symmetric function at t = tc with time support [tc-ts, tc+ts]. The SDC(tc,ts) is the ratio of the energy of (A-B) to the total energy of A and B.

The range of SDC in (3) is [0, 2] which does not meet common sense. The equation is modified to shift its range to [-1,1] where -1represents odd-symmetry, 0 represents asymmetry, and 1 represents even-symmetry as in (4).

$$SDC(t_{c}, t_{s}) = 1 - \frac{\int_{0}^{t_{s}} (f(t_{c} - \tau) - f(t_{c} + \tau))^{2} d\tau}{\int_{-t_{s}}^{t_{s}} f^{2}(t_{c} - \tau) d\tau}$$
(4)

SDC is independent to input signal amplification. Suppose a signal, f(t), is evensymmetry around t = 0 i.e. $\{f(t) = f(-t)\}_{t \in [-t_s, t_s]}$. Another signal, g(t), is equal to f(t) but asymmetric due to $\{e(t)\}_{t \in [0, t_s]}$:

$$g(t) = \begin{cases} f(t) & t \in [-t_s, 0] \\ f(t) + e(t) & t \in (0, t_s] \end{cases}$$
(5)

then *SDC* at t = 0 with support [- t_s , t_s] is:

$$SDC(0,t_{s}) = 1 - \frac{\int_{0}^{t_{s}} e^{2}(\tau) d\tau}{\int_{0}^{t_{s}} 2f^{2}(\tau) + 2f(\tau)e(\tau) + e^{2}(\tau)d\tau}$$
(6)

If the signal is then amplified by a factor of *A*:

$$g(t) = \begin{cases} Af(t) & t \in [-t_s, 0] \\ Af(t) + Ae(t) & t \in (0, t_s] \end{cases}$$
(7)

the SDC becomes

$$SDC(0,t_{s}) = 1 - \frac{A^{2} \int_{0}^{t_{s}} e^{2}(\tau) d\tau}{\int_{0}^{t_{s}} 2A^{2} f^{2}(\tau) + 2Af(\tau)Ae(\tau) + A^{2}e^{2}(\tau)d\tau}$$
(8)

By canceling out the amplification factors, *A*, equation (8) proves that SDC can measure the level of symmetry, independent to the strength of input signal or transient.

The ability to measure symmetry independent to signal strength may create problem if the input signal has too many unexpected small ripples (see Fig. 3). To avoid measuring SDC of unwanted small transients, a threshold level, *th*, is added to the equation to ignore transients with energy less than the threshold level.

$$SDC(t_{c},t_{s}) \qquad if \int_{-t_{s}}^{s} f^{2}(t_{c}-\tau)d\tau > th$$

$$SDC_{th}(t_{c},t_{s},th) = \begin{cases} 0 \qquad else \end{cases}$$
(9)

Equation (8) and (9) are the mathematic definition of SDC.

Fig. 2 shows $SDC_{th}(t, 0.25, 0.1)$ of evennearly even-symmetric, symmetric, oddsymmetric, nearly odd-symmetric and asymmetric transients located at $t = 0.75 \ s, 1.75$ s, 2.75 s, 3.75 s, and 4.75 s, respectively. The SDC of the first transient, $SDC_{th}(0.75, 0.25, 0.1)$, is 0.99. It means that the transient is 99% evensymmetry. The second transient is only 90% even-symmetry, while the third to fifth transients are 99% odd-symmetry, 92% odd-symmetry, and 0% symmetry, respectively. The figure shows how SDC can measure various types and levels of symmetry.

Fig. 3 shows the necessity of using threshold. It shows SDC of a signal with a symmetric transient at $t = 0.475 \ s$ and small noises. When threshold was set to zero (no threshold) the SDC of the investigated transient was obscured by a large number of SDCs of the noises (Fig. 3b). When a threshold value of 5 was used, the SDC of the noises were removed (Fig. 3c).



Figure 2. The SDC of various types and levels of symmetry.



Figure 3. a) A signal with an even-symmetric transient added with noises. b) The $SDC_{th}(t,0.125,0)$, c) The $SDC_{th}(t,0.125,5)$.

IV. MEASURING PROCEDURES AND EXPERIMENT

The procedure to measure similarity between a wavelet function, $\psi_{s,\sigma}$, and a transient located at $t = t_c$ in an input signal, f(t), is as follows:

- 1. Apply WT to f(t) using the selected wavelet function, $\psi_{s,\sigma}$, to the whole time span of f(t).
- 2. Calculate $SDC_{th}(t_c, t_s, th)$ of the wavelet coefficients at time location $\sigma = t_c$. The time support parameter, t_s , should be half of the selected wavelet function's time support or

half of the interested transient's time support. Use an appropriate threshold, *th*, to ignore small ripples in wavelet coefficients.

3. The value of $SDC_{th}(t_c, t_s, th)$ indicates the degree of shape similarity between the selected wavelet function and the transient. The closest the value to *1*, the more similar the two functions.

The parameter and procedure was applied to electrocardiograph (ECG) signal [7, 20] to find a wavelet function that has the most similar shape to T-waves (marked with 'T' in Fig. 4a). An ECG signal, downloaded from MIT-BIH PhysioBank database record aami3a.dat (AAMI-EC13) [21] was used in this experiment (Fig. 4a). The signal was re-sampled with a sampling rate of 360 Hz. Wavelet coefficients were calculated using various wavelet functions. However, the results of only three wavelet functions are presented in this paper (i.e. db2 at scale 28, Gaus2 at scale 8, and Mexh at scale 12) due to their significant results. The SDC calculation was then applied to all wavelet coefficients with a half time support of 0.158 s and a threshold value of 0.1. The results (Fig. 4b-d) suggested that db2 at scale 28 is the wavelet function with the most similar shape to T-waves. The average $SDC_{th}(t, 0.158, 0.1)$ of the four T-waves when calculated using db2 wavelet at scale 28 was 0.915. The value was higher than that of Gaus2 wavelet at scale 8 and Mexh wavelet at scale 12 (0.88,and 0.82. respectively). The experiment suggests that the parameter and the procedure can be used to find wavelet function that has the most similar shape to an interested transient.

V. CONCLUSION

This paper introduces a new parameter called *'symmetric distance coefficient'* (SDC) and the procedure to measure shape similarity between a wavelet function and a transient in a signal. The parameter measures the similarity by measuring the symmetric pattern in wavelet coefficient. It is based on the fact that wavelet transform of a transient that has the same shape as a wavelet function is always symmetric. The parameter is useful as a guidance to select suitable wavelet

function for a specific transient in a signal or application.

The paper also presents an experiment to demonstrate the procedure and the parameter's ability to measure shape similarity between a wavelet function and transients in signal. The experiment demonstrates how the parameter can be used to find a wavelet function that has the most similar shape to T-waves in ECG signal.



Figure 4. a) ECG signal (MIT-BIH aami3a.dat – AAMI EC13) with sampling rate 360 Hz, b) – d) The $SDC_{th}(t, 0.158, 0.1)$ calculated on wavelet coefficients using Db2 at scale 28, Gaus2 at scale 8, and Mexh at scale 12, respectively.

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