澳門大學
UNIVERSIDADE DE MACAU
UNIVERSITY OF MACAU

WAVELET NEURAL NETWORKS

THE FUSION OF HC AND SC FOR COMPUTERIZED PHYSIOLOGICAL SIGNAL INTERPRETATION

LI Bing Nan

(*B.Eng*. Southeast University; *M. Sc*. University of Macau)

A thesis submitted for the fulfillment of

the requirements of the degree of

DOCTOR OF PHILOSOPHY

in

ELECTRICAL AND ELECTRONICS ENGINEERING

Faculty of Science and Technology
University of Macau

November 2009

Wavelet Neural Networks:

The Fusion of HC and SC for Computerized Physiological Signal Interpretation

---

LI Bing Nan

Department of Electrical and Electronics Engineering
Faculty of Science and Technology
University of Macau
Av. Padre Tomás Pereira S. J., Taipa, Macao, China

* The works in this dissertation were financially supported in part by the Macau Science and Technology Development Fund, and in part by the University of Macau Research Committee.

In presenting this dissertation in partial fulfillment of the requirements for a PhD's degree at the University of Macau, I agree that the Library and the Faculty of Science and Technology shall make its copies freely available for inspection. However, reproduction of this dissertation for any purposes or by any means shall not be allowed without my written permission. Authorization is sought by contacting the author at

Address:
Department of Electrical & Electronics Engineering, Faculty of Science and Technology, University of Macau, Taipa, Macau

Telephone: (853) 83974518

Fax: (853) 28835928

Email: me@bingoon.org

Signature ______________________

Date ______________________

ABSTRACT

WAVELET NEURAL NETWORKS

THE FUSION OF HC AND SC FOR COMPUTERIZED PHYSIOLOGICAL SIGNAL INTERPRETATION

by

LI Bing Nan

Thesis Supervisor: Prof. DONG Ming Chui

Thesis Co-supervisor: Prof. VAI Mang I

Department of Electrical and Electronics Engineering, University of Macau, Taipa, Macau

The works presented in this dissertation originate from our years of research on cardiovascular health monitoring at home. Different prototyping systems have been developed in our group for cardiovascular health monitoring. However, it is found in our practice that computerized interpretation of the recorded cardiovascular physiological signals is far more challenging than expected. The biggest challenge comes from the intrinsic physiological signal variability due to pathophysiological artifacts, instrumental inaccuracy and operational inconsistency. All of them alter the morphologies and rhythms of cardiovascular physiological signal substantially. At the same time, there is yet no unanimous solution to discriminate and eliminate abovementioned variability in cardiovascular physiological signals.

This dissertation is focused on integrating hard computing (HC) and soft computing (SC) for computerized physiological signal interpretation. Neural networks are chosen as the delegate of SC for adaptive clustering and supervised classification. Among various HC paradigms, wavelet transform is a well-established technology for unified time-frequency analysis. To attack physiological signal variability, we are interested in the essential components by means of wavelet analysis. Those components are supposed resistant to noises and artifacts. Nevertheless, there is yet no unanimous criterion for the choice of essential wavelet components. Two criteria were examined and evaluated in this dissertation for adaptive wavelet modeling. The first one is oriented to energy maximization. It attempts to select out those strong wavelet components. Actually, many popular schemes of adaptive wavelet modeling, such as wavelet scale maxima, relative wavelet energies and regional wavelet entropies, exactly follow this energy-oriented criterion. The second criterion directing adaptive wavelet modeling is oriented to morphological similarity. In essence, it is desired

to optimize wavelet modeling to approximate the original physiological signals accurately with a compact representation. The refined wavelet components are supposed optimal to the essential signal components, meanwhile are resistant to noises and artifacts. The paradigms of wavelet shrinkage, matching pursuits and wavelet regression networks obey such morphology-oriented criterion for adaptive wavelet modeling.

All of them were further examined in comparison with the fully integrated wavelet networks for adaptive clustering and supervised classification of cardiovascular physiological signals. In general, a wavelet network replaces the neuronal transfer functions in conventional neural networks by wavelet basis functions. Hence the optimization of wavelet modeling and neural networks can be unified as a whole. In practice, we found that wavelet networks suffer from many challenging issues in system architecture, network initialization, optimal evolution, and so forth. On the contrary, the modular integration of wavelet analysis and neural networks owns structural simplicity and implemental flexibility. Nevertheless, the morphology- or energy-oriented paradigm of adaptive wavelet modeling keeps blind to the subsequent clustering or classification. In other words, their performance can not be guaranteed as an overall system for physiological signal interpretation. Therefore we proposed two novel wavelet modeling strategies in this dissertation.

The first scheme, termed as principal wavelet modeling (PWM), incorporates the theories and methods of principal component analysis into adaptive wavelet modeling. The choice of wavelet components are based on neither energy maximization nor morphological similarity, but their clustering distributions in the unified time-frequency space. Theoretically speaking, the PWM is optimal for adaptive clustering of cardiovascular physiological signals. On the other hand, we took advantages of the theories and methods of linear discriminant analysis for the second paradigm of adaptive wavelet modeling, termed as discriminant wavelet modeling (DWM). The adaptive wavelet modeling is hereby oriented to classification optimization directly.

The performance was validated carefully in both small- and large-scale benchmark databases. In terms of ECG beat clustering, the wavelet neural network using novel PWM and FCM achieved the accuracy 64.7%, which was better than those morphology-oriented HBF (57.5%) and MP (53.4%). Coming to ECG classification, the wavelet neural network based on the novel DWM and *k*NN (error rate 10.34$\pm$0.35%) was fairly good against the energy-oriented WSM (13.31$\pm$0.30%) and the morphology-oriented MP (18.75$\pm$0.67%), but worse than the morphology-oriented HBF (8.45 $\pm$ 0.26%). As a conclusion, neither morphology- nor energy-oriented adaptive wavelet modeling is able to guarantee the global performance for optimal clustering and classification. In contrast, the novel PWM and DWM are robust against physiological signal variability, thus effective for computerized physiological signal interpretation.

ACKNOWLEDGEMENTS

First and foremost, I am truly indebted to my supervisors – Prof. DONG Ming Chui and Prof. VAI Mang I – for their invaluable mentorship. Only with their patient guidance and endless support, I had the courage to spend seven years on my graduate studies and achieve some decent results. To be frank, Prof. DONG and Prof. VAI offered me the all-round helps, from living allowance to technical facilities, during the past seven years.

The Institute of Systems & Computer Engineering (INESC-Macau) and the Department of Electrical & Electronics Engineering offered me a comfortable and friendly environment, which are of great help to my doctoral study and research. Please allow me to thank the staff in both institutes, including Prof. HAN Ying Duo, Prof. RUI Martins, Prof. LI Yi Ping, Prof. MOK Kai Meng, Prof. QIAN Tao, Prof. CHENG Weiji, Dr. MAK Peng Un, Dr. CHAN Iat Neng, Dr. WONG Chi Kong, Dr. CHAO Sam, Dr. WONG Fai, Dr. WAN Feng, Dr. DAI Ningyi, Mr. CHEANG Sek Un, and many many others.

The works presented in this dissertation are benefited from several research projects supported by the Macau Science and Technology Development Fund (Grant No: 007/2006/A1 and 014/2007/A1) and the University of Macau Research Committee (Grant No: RG071/04-05S/DMC/FST, RG074/04-05S/VMI/FST and RG061/06-07S/VMI/FST). Their generous financial supports are in particular appreciated.

The colleagues in my research group – Mr. LEI Wei Kei, Ms. FU Binbin, Mr. SHI Jun, Mr. FEI Xiaolei, Mr. IEONG Chio In, and Mr. PUN Sio Hang – are worthy of my words for their friendliness, technical supports as well as inspiring discussion. What a happy time to study and work with all of you. In particular, I hope to point out that Mr. LEI and Ms. FU assisted me a lot in my research and experiments.

Finally, but not all, I would like to express my wholehearted gratitude to my family and especially my family-in-law. As a matter of fact, without their understanding, patience and consistent support, what I have done would be nothing at all. To my heart, I hope to dedicate this dissertation to my loves, Ms. SHI Mian and Ms. LI Siyuan.

LI Bing Nan

Nov 2009

TABLE OF CONTENTS

LIST OF FIGURES

ID PAGE NUMBER

LIST OF TABLES

LIST OF ABBREVIATIONS

ABP	Arterial Blood Pressure
AESC	Arial Escape Beats
AR^2	Adjusted R-square
CVD	Cardiovascular Diseases
CVS	Cardiovascular System
DBP	Diastolic Blood Pressure
ECG	Electrocardiograms
ES	Expert System
FCM	Fuzzy C-Means
FL	Fuzzy Logics
FN	False Negatives
FP	False Positives
GA	Genetic Algorithms
HBF	Hermite Basis Function
HC	Hard Computing
HRV	Heart Rate Variability
IQR	Inter-Quartile Range
***k*NN**	*k*-Nearest Neighbor
MAP	Mean Arterial Pressure
MLP	Multilayer Perceptrons
MP	Matching Pursuits
NN	Neural Networks
ANN	Artificial Neural Network
ART	Adaptive Resonance Theory
BPV	Blood Pressure Variability
AWT	Adaptive Wavelet Modeling
CPS	Cardiovascular Physiological Signal
CWN	Competitive Wavelet Network
CWT	Continuous Wavelet Transform
DWM	Discriminant Wavelet Modeling
DWT	Discrete Wavelet Transform
FLD	Fisher Linear Discriminant
GCV	Generalized Cross-Validation
IIR	Infinite Impulse Response
LBBB	Left Bundle Branch Block
MAD	MIT/BIH Arrhythmia Database
MGH	MGH/MF Waveform Database
MRA	MultiResolution Analysis
PAC	Premature Atrial Contractions
PCA	Principal Component Analysis
PNN	Probabilistic Neural Network
PUD	PUlse waveform Delineator
PVC	Premature Ventricular Contractions
PWM	Principal Wavelet Modeling

RBF Radial Basis Function

SBP Systolic Blood Pressure

SC Soft Computing

SOM Self-Organizing Maps

TP True Positives

VF Ventricular Flutter

WBF Wavelet Basis Function

WP Wavelet Package

WT Wavelet Transform

QMF Quadrature Mirror Filters

RBBB Right Bundle Branch Block

RWE Relative Wavelet Energies

SVM Support Vector Machines

SVPB Supraventricular Premature Beats

VEB Ventricular Escape Beat

WCN Wavelet Classification Network

WRN Wavelet Regression Network

WSM Wavelet Scale Maxima