



TABLE OF CONTENTS

ABSTRACT	vi
ABSTRAK	ix
DEDICATION	xiii
ACKNOWLEDGEMENT	xiv
NOMENCLATURE	xvi
TABLE OF CONTENTS	xix
LIST OF FIGURES	xxiii
LIST OF TABLES	xxxi
CHAPTER 1	1
INTRODUCTION	1
1.1 The Role of Reservoir Characterization in Managing an Oil Field	1
1.2 Geostatistics	4
1.3 Wavelet Transform	9
1.4 Problem Description	13
1.5 Objective of the Research	20
1.6 Originality of the Research	21
1.7 Contribution of the research	21
CHAPTER 2	23
LITERATURE REVIEW	23
2.1 Wavelet Application in seismic data compression.	23
2.2 Wavelet Application in Pressure Transient Analysis	25
2.3 Wavelet in Inverse Problem Application	29
2.4 Wavelet Application in Detecting Reservoir Connectivity	32
2.5 Wavelet application in Earth Model Scale-up/Scale-down Process	34
2.6 Wavelet application in Geostatistics	41
CHAPTER 3	45
THEORETICAL BACKGROUND	45
3.1 Univariate Description of Data	45



3.1.1 Frequency and Cumulative Distribution	45
3.1.2 Univariate Description of Data	47
3.1.2.1 Measure of Location	48
3.1.2.2 Measure of Dispersion	51
3.1.2.3 Measure of Shape	54
3.2 Bivariate Description of Data	56
3.2.1 Expectation	56
3.2.2 Variance as an Expected Value	58
3.2.3 Bivariate Distribution	58
3.2.4 Covariance	60
3.3 Regionalized Variable and the Concept of Stationarity	61
3.3.1 Regionalized Variables	61
3.3.2 Stationarity	62
3.3.3 Estimation of the Variogram	63
3.4 Linear Regression and Kriging	74
3.4.1 Unconstraint Linear Estimator and Simple Kriging	75
3.5 Filter	78
3.5.1 Formulation of the Wiener Filter Problem	79
3.5.2 Normal Equations in Wiener Filter	81
3.5.3 Wiener Filter and Kriging Equations	86
3.5.4 Kalman Filter and Kriging Equations	86
3.6 Wavelets	87
3.6.1 What are Wavelets ?.	87
3.6.2 What are Basis Functions?	93
3.6.3 Signal	95
3.6.4 The Haar Wavelet Family	96
3.6.5 Numerical Example of Processing Signals	103
3.6.6 Filters and Filter Banks	106
3.6.7 Multi Resolution Analysis	107
3.6.8 Wavelet Application in Linear System Problem Solution	108
3.7 Adaptive process	109
3.7.1 Definition and Characteristics of Adaptive Process	109
3.7.2 General Properties of Adaptive Process	111
3.7.3 Open- and closed-loop system	112
3.7.4 The Adaptive Linear Combiner	116
3.7.4.1 Input Signal and Weight Vectors for Linear Combiner	117
3.7.4.2 Desired and Response Error	120
3.7.4.3 The Performance Function	121
3.7.4.4 Gradient and Minimum Mean-Square Error	125
3.7.4.5 Decorrelation of Error and Input Components	127
3.7.5 Methods of Searching the Performance Surface	128
3.7.5.1 Basic Ideas of Gradient Search Methods	128



3.7.5.2 A Simple Gradient Search Algorithm and its Solution	130
3.7.5.3 Stability and Rate Convergence	133
3.7.5.4 The Learning Curve	135
3.7.5.5 Gradient Search by Newton's Method	136
3.7.5.6 Newton's Method in Multidimensional Space	140
3.7.5.7 Gradient Search by the method of Steepest Decent	142
3.7.5.8 Comparison of Learning Curves	149
3.7.6 The LMS Algorithm	152
3.7.6.1 Derivation of the LMS Algorithm	153
3.7.6.2 Convergence of the Weight Factor	155
3.7.6.3 Learning Curve	155
3.8 Closure	156
CHAPTER 4	158
METHOD OF THE RESEARCH	158
4.1 Simple Kriging	158
4.1.1 Numerical Example	163
4.2 Wavelets and Wavelet Transform	167
4.2.1 Low-pass Filter = Moving Average	168
4.2.2 High-pass Filter = Moving Difference	170
4.2.3 Filter Banks = Low-pass and High-pass	171
4.2.4 Numerical Example	172
4.3 Adaptive Wavelet Kriging	175
4.4 Closure	178
CHAPTER 5	179
PROCEDURE OF THE RESEARCH	179
5.1 Data Preparation and analysis	179
5.2 The algorithm of Kriging (KRG)	182
5.3 The algorithm of Kriging with Wavelet (KRWL)	185
5.4 The algorithm of Kriging with Adaptive Wavelet (KRAWL)	188
5.5 Result Examples	193
5.5.1 Synthetic Data	193
5.5.2 Real Data	196
5.6 Closure	201
CHAPTER 6	202
RESULTS AND DISCUSSIONS	202
6.1 Results	202
6.2. Discussion	209
6.3 Application to Other Data Set	215
6.4 Closure	217



CHAPTER 7	219
CONCLUSIONS AND SUGGESTIONS	219
7.1 Conclusions	219
7.2 Suggestions	220
REFERENCES	222
Appendix A	227
The Theory of Expectation	227
A.1 Expected Value of a Random Variable	228
A.2 Expected value of a function of a Random Variable	230
Appendix B	235
The History of Wavelets	235
Appendix C	238
The List of the Cases	238
Appendix D	263
The Picture of the Cases	263
Appendix E	264
Comparison of Three Kriging Methods to Synthetic data	264
CURRICULUM VITAE	266

LIST OF FIGURES

Figure 1-1 The high level of reservoir management cycle.	3
Figure 1-2 Conceptual representation of variogram.	8
Figure 1-3 Fourier Transform (after Misiti et al, 2002)	11
Figure 1-4 Short-Time Fourier Transform – STFT (after Misiti et al, 2002)	11
Figure 1-5. Wavelet transform (after Misiti, 2002).	12
Figure 2-1 Type curve analysis of the well test (after Soliman et.al., 2000)	26
Figure 2-2 Normalized wavelet coefficient (after Soliman et al, 2000)	27
Figure 2-3 Zoom-in of the wavelet coefficient (after Soliman et al, 2000).	28
Figure 2-4 Synthetic permeability field (after Lu and Horne, 2000)	31
Figure 2-5 Result of inverse problem approach with Haar wavelet (after Lu and Horne, 2000).	31
Figure 2-6 Result of conventional approach (after Lu and Horne, 2000).	32
Figure 2-7 Barrier interpretation of the inter well cross correlation of wavelet coefficient (after Jansen and Kelkar, 1997).	33



Figure 2-8 Comparison of oil and water production from fine and coarse grid systems (after Chu et al, 1996).	36
Figure 2-9 Comparison of water cut production from fine and coarse grid systems (after Chu et al, 1996).	36
Figure 2-10 Schematic of pyramidal algorithm (after Panda et al, 1996).	38
Figure 2-11 Permeability-average data at different level of scale-up (after Panda et al, 1996).	39
Figure 2-12 Original fine scale permeability (after Panda et al, 1996).	40
Figure 2-13 Scaled-up using pressure-solver (after Panda et al, 1996).	40
Figure 2-14 Scaled-up using wavelet-based solver (after Panda et al, 1996).	41
Figure 2-15 (a) The variogram used to model NVI; (b) the map resulted from kriging using variogram in (a) (after Oliver et al, 2000)	42
Figure 2-16 Wavelet reproduction using Daubechies 6. (a) from scaling function that can be specified by low-pass filter; (b) from wavelet function that can be specified by high pass filter (after Oliver et al, 2000).	43



Figure 2-17 Kriging reproduction. (a) longer variogram model (than that of in fig 2-16); (b) shorter variogram model (than that of in fig 2-16) (after Oliver et al, 2000).	44
Figure 3-1 Distribution and its cumulative.	47
Figure 3-2 Kurtosis (after Spiegel, 1996)	56
Figure 3-3 Variogram presented as a moment of inertia (after Journel, 1989).	60
Figure 3-5 Parabolic behavior near origin.	67
Figure 3-6 Linear behavior near origin.	68
Figure 3-7 Nugget Effect near origin.	68
Figure 3-8 Pure Nugget effect - white noise.	69
Figure 3-9 Comparison of three variogram models.	71
Figure 3-10 Variogram of Geometric Anisotropy (a) The variogram; (b) Rose diagram showing the plot of ranges (after Goovaert, 1997).	73
Figure 3-11 Variogram of Zonal Anisotropy (after Goovaert, 1997).	73
Figure 3-12 Tapped-delay-Line filter (after Haykin, 1984)	80
Figure 3-13 Wavelets from Daubechies family (after Vidakovic and Mueller, 1991).	89
Figure 3-14 Dilation effect to the signal (after Misiti et al, 2002).	90
Figure 3-15 Translation effect to the signal (after Misiti et al, 2002).	90



Figure 3-16 (a) the function f , (b) Fourier based approximation with 17 terms (c) Wavelet based approximation with 17 terms (after Nielsen, 1998)	92
Figure 3-17 Image compression, original image (left) and its decompression image (right) (after Misiti et al, 2002).	93
Figure 3-18 The graph of wavelet $\psi_{1,1}$.	102
Figure 3-19 The output of linear system and adaptive system (after Widrow and Stearns, 1985)	112
Figure 3-20 Open loop adaptation (after Widrow and Stearns, 1985)	114
Figure 3-21 Closed loop adaptation (after Widrow and Stearns, 1985)	115
Figure 3-22 General form of adaptive linear combiner (after Widrow and Stearns, 1985)	117
Figure 3-23 Adaptive linear combiner in the form of single-input adaptive transversal filter (after Widrow and Stearns, 1985)	118
Figure 3-24 Multiple-input adaptive linear combiner (after Widrow and Stearns, 1985)	120
Figure 3-25 Multiple-input adaptive linear combiner with desired response and error signal (after Widrow and Stearns, 1985)	121
Figure 3-26 Portion of a two dimensional quadratic performance (after Widrow and Stearns, 1985)	124
Figure 3-27 Gradient search of univariable performance surface (after Widrow and Stearns, 1985)	129
Figure 3-28 Weight adjustment for different values of geometric ratio r . With $r = 0$ (Newton Method), w^* is reached in on iteration (after Widrow and Stearns, 1985)	134



Figure 3-29 The “learning curve” is a plot of the mean-square error versus k (after Widrow and Stearns, 1985)	136
Figure 3-30 Newton’s Method for finding a zero of $f(w)$ (after Widrow and Stearns, 1985).	138
Figure 3-31 Illustration of Newton’s Method with $\mu = 1$ and 2 weights (after Widrow and Stearns, 1985)	142
Figure 3-32 Steepest-descent algorithm with two weights (after Widrow and Stearns, 1985).	146
Figure 3-33 Learning curve of Newton’s method applied to a multidimensional quadratic performance function (after Widrow and Stearns, 1985)	150
Figure 3-34 Learning curve of method of steepest descent applied to multidimensional quadratic performance function (after Widrow and Stearns, 1985).	151
Figure 3-35 The adaptive linear combiner (a) in general form; (b) as a transversal filter (after Widrow and Stearns, 1985)	154
Figure 3-36 Learning curve for LMS estimated by averaging 500 runs (after Widrow and Stearns, 1985).	156
Figure 4-1 Wavelet Filter Tree	167
Figure 4-2 Wavelet application in Kriging process.	174
Figure 4-3 The LMS algorithm in general form (after Widrow and Stearns, 1985)	177
Figure 5-1 Synthetic data used in this research, X and Y are normalized position.	180
Figure 5-2 Noisy synthetic data (a) original data, (b) 5% noise, (c) 25% noise, X and Y are normalized position.	181
Figure 5-3 Relative well location in normalized map, X and Y are normalized position.	181



Figure 5-4 Workflow of KRG	184
Figure 5-5 Workflow of KRWL	187
Figure 5-6 Workflow 1 of KRAWL	191
Figure 5-7 Workflow 2 of KRAWL	192
Figure 5-8 Comparison between synthetic data and Kriging estimate for separable case. X and Y axes are normalized position.	193
Figure 5-9 Comparison between synthetic data and Kriging estimate for non-separable case. X and Y axes are normalized position.	194
Figure 5-10 Comparison between (a) 5% noise synthetic data, (b) Kriging estimate, and (c) Kriging with wavelet estimate. X and Y axes are normalized position.	195
Figure 5-11 Comparison between (a) 25% noise synthetic data, (b) Kriging estimate, and (c) Kriging with wavelet estimate. X and Y axes are normalized position.	195
Figure 5-12 Maps generate with Kriging technique and wavelet (Db4). X and Y axes are normalized position.	197
Figure 5-13 Maps generate with Kriging technique and Riyad wavelet. X and Y axes are normalized position.	197
Figure 5-14 Maps generate with Kriging technique and adaptive wavelet.	198
Figure 5-15 Nonzero component of covariance matrix after wavelet transform using Db4.	199
Figure 5-16 Nonzero component of covariance matrix after wavelet transform using Riyad2 wavelet.	199

Figure 5-17 Nonzero component of covariance matrix after wavelet transform using adaptive wavelet.	200
Figure 6-1 Effect of wavelet to the compression ratio for variogram range 0.1	202
Figure 6-2 Effect of wavelet to the compression ratio for variogram range 0.5	203
Figure 6-3 Effect of wavelet to the compression ratio for variogram range 1. Note that the other wavelets resulting singular transformed covariance matrix	203
Figure 6-4 Compression ratio at variation variogram range for Riyadh2 wavelet.	204
Figure 6-5 The optimized wavelet resulted from adaptive process for various variogram	206
Figure 6-6 Effect of different variogram range to the compression ratio for adaptive wavelet.	207
Figure 6-7 Effect of different variogram range to the bandwidth of the transformed matrix for adaptive wavelet.	208
Figure 6-8 Effect of different variogram range to the inversion flops ratio for adaptive wavelet.	208
Figure 6-9 Correlation between flops and nonzero covariance matrix.	210
Figure 6-10 Correlation between flops and bandwidth.	210
Figure 6-11 Comparison of flops requirement for several kriging algorithms.	212
Figure 6-12 Adaptive wavelet application in anisotropic case (anisotropic factor 2). X and Y are normalized position.	216



- Figure 6-13 Adaptive wavelet application in predicting reservoir tops of Rindu. X and Y are Normalized position. 216
- Figure 6-14 Adaptive wavelet application in predicting porosity in Balam South Telisa Field. X and Y are normalized position. 217
- Figure E-1 Synthetic data used as reference, X and Y are normalized position. 264
- Figure E-2 Figure E-2 Comparison of the kriging, kriging with Riyad wavelet and kriging with adaptive wavelet. The left pictures are the maps and the right pictures are the shape of the non-zero component of the covariance matrix to invert. X and Y are normalized position. 264



LIST OF TABLES

Tabel 2-1 Level decomposition using Daubechies-4 versus coefficient of correlation (after Sullera and Horne, 1999)	34
Table 3-1 Effect of μ on convergence of the single-weight gradient search process (after Widrow and Stearns, 1985)	134
Table 5-1 Comparison between kriging and kriging with wavelet techniques	200
Table 6-1 Wavelet coefficients resulted from adaptive wavelet method at various variogram ranges.	206
Table 6-2 List of correlations to estimate flops requirement for single point kriging with Riyad2 wavelet and kriging with adaptive wavelet.	214