Dedicated to my family and well wishers

Declaration

I do hereby declare that the thesis entitled "**NSST-based feature descriptors for remote sensing and bio-medical image retrieval**"being submitted to the Department of Electronics and Communication Engineering, School of Engineering, Tezpur University is a record of original research work carried out by me. All sources of assistance have been assigned due acknowledgement. I also declare that neither this work as a whole nor a part of it has been submitted to any University or Institute for award of any other degree or diploma. Any violation of the above declaration will take disciplinary action by the university.

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Certificate of the Supervisor

This is to certify that the thesis entitled "**NSST-based feature descriptors for remote sensing and bio-medical image retrieval**"submitted to the School of Engineering, Tezpur University in partial fulfillment for the award of the degree of Doctor of Philosophy in the Department of Electronics and Communication Engineering is a record of research work carried out by Ms. Hilly Gohain Baruah under my supervision and guidance.

All help received by her from various sources have been duly acknowledged. No part of this thesis has been submitted elsewhere for award of any other degree.

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Certificate of External Examiner and ODEC

The examiners of Oral Defence Evaluation Committee (ODEC) certify that the thesis entitled "**NSST-based feature descriptors for remote sensing and bio-medical image retrieval**"submitted by Hilly Gohain Baruah, research scholar, Department of Electronics and Communication Engineering, School of Engineering, Tezpur University in partial fulfillment for the award of the degree of Doctor of Philosophy, has been examined by us on ..... and found to be satisfactory.

Thereby, the committee recommends for the award of the degree of Doctor of Philosophy.

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(Hilly Gohain Baruah), Place: Tezpur, Assam, India

List of Figures

1.1 Block diagram of a CBIR framewrok 3

3.1 The geometric impacts of parabolic scaling and shearing with fixed parameter λ and several parameter ω_o (a)$\omega_o = 0$ (b)$\omega_o = 1/4$ and(c) $\omega_o = 1/2$ 40

3.2 The frequency support of the classical shearlets $\hat{\psi}_{\lambda,\omega_o,\tau}$ for different λ and ω_o 42

3.3 The frequency tiling induced by the discrete shearlets $\hat{\psi}_{p,q,r}$ 43

3.4 The illustration of the Laplcian filter and directional filtering . . . 44

3.5 Subbands obtained through two-level NSST decomposition of a sample RS image 44

3.6 (a-c) and (d-f) shows the plots corresponding to the NSST detail subbands of image 1 and image 2 from WHU-RS19 respectively . . 45

3.7 Block diagram of the NSST-SNIG based feature extraction approach 46

3.8 The Laplacian, BKF and SNIG pdf's fitted to the empirical histogram in log state for one finest NSST subband of six different images (Two each from WHU-RS19, AID and PatternNet) 49

3.9 The sample image taken from individual classes of WHU-RS19 dataset 51

3.10 The sample image taken from individual classes of AID dataset . . 51

3.11 The sample image taken from individual classes of PattenNet dataset 52

3.12 Example computation of MAP considering two query images with different number of relevant images in dataset 54

3.13 The per class average precision comparison of various schemes for WHU-RS19 57

3.14 The per class average precision comparison of various schemes for AID dataset 57

3.15 The per class average precision comparison of various schemes for PatternNet dataset 58

3.16 The P-R curve for (a)WHU-RS19, (b)AID and (c) PatternNet dataset 59

3.17 Images retrieved for some of the classes of WHU-RS19 dataset(The black-bordered query image is on the left, while the top five retrieval results are on the right.) 60

3.18 The NSSTds-3DLTP descriptor's functional block diagram in an image retrieval framework 63

3.19 Log histogram of one finest NSST subband of six different images (Two each from WHU-RS19, AID and PatternNet) where Laplacian, BKF, SNIG, and LM pdfs fitted to empirical histogram in log domain 67

3.20 Illustration of LBP and LTP computation for an example image . . 69

3.21 A sample example for 3D-LTP calculation 70

3.22 The resultant pattern maps generated from an example image using 3D-LTP operation (a) Original image (b) Upper-LTP pattern map generated from R-channel, (c)Lower-LTP pattern map generated from R-channel,(d) Upper-LTP pattern map generated from G-channel,(e) Lower-LTP pattern image generated from G-channel,(f) Upper-LTP pattern map generated from B-channel,(g)Lower-LTP pattern map generated from B-channel 71

3.23 The per class average precision comparison of the NSSTds-3DLTP with other techniques for WHU-RS19 dataset 74

3.24 The per class average precision comparison of the NSSTds-3DLTP with other techniques for AID 75

3.25 The per class average precision comparison of the NSSTds-3DLTP with other techniques for PatternNet dataset 75

3.26 Image classes for which global NSSTds alone (first-row) and local 3D-LTP alone (second-row) produce superior results when compared to one other. 76

3.27 The P-R curve obtained for different datasets 77

3.28 Retrieved images obtained for few input query images taken from multiple classes, using NSSTds-3DLTP (Input query image, correct retrieved results and wrong retrieved results are enclosed in Black, Green and Red coloured boxes respectively for more clarity.) 79

4.1 An overview of NSST-LBPDAP based image retrieval system 83

4.2 (a)Example Image (b)The eight bit-planes BB_0(least significant) to BB_7 (most significant) 85

4.3 Bit-plane slices of a given image from TCIA-CT dataset after bit-plane decomposition 85

4.4 An example computation of LBPDAP (a)Example image, (b)Position of the bit-plane neighbors, (c)Calculation of adder pattern, (d)Weights, (e)Obtained encoded bit-planes and(f)Computation of LBPDAP 87

4.5 Sample images of different classes of NEMA-CT 91

4.6 Sample images of different classes of TCIA-CT 91

4.7 Sample images of different classes of YORK-MRI 91

4.8 Comparison of NSST-LBPDAP with other schemes for NEMA-CT . 92

4.9 Comparison of NSST-LBPDAP with other schemes for TCIA-CT . 94

4.10 Comparison of NSST-LBPDAP with other schemes for YORK-MRI 95

4.11 The retrieved images for LDEP, LWP, LBDP, LBDISP, LBPDAP, LBPANDP, CSLBCoP, Cont.-TrP, and NSST-LBPDAP techniques for one sample query image (for top ten image matches),(The image in the black box is a query image; the images in the green boxes were correctly retrieved; the images in the red boxes were incorrectly retrieved.)) 97

4.12 The illustration of distinguishing conduct of LBPDAP, LBDP, LBPANDP, LBDISP and NSST-LBPDAP features in discriminating interclass and intraclass images belonging to TCIA-CT 98

4.13 An overview of NSST-LBNDP based image retrieval system 100

4.14 Bit-plane encoding of a sample image 102

4.15 % ARP and %ARR comparison for NEMA-CT 106

4.16 % ARP and %ARR comparison for TCIA-CT 106

4.17 % ARP and %ARR comparison for YORK-MRI 107

4.18 Retrieved images obtained for the top 15 image matches in the NEMA-CT database for LDEP, LWP, LBDP, LBDISP, LBPDAP, LBPANDP, CSLBCoP, Cont.-TrP, and NSST-LBNDP descriptors. (The image inside the red box is incorrectly retrieved, the image inside the green box is correctly retrieved, and the image inside the black box is a query image.) 110

4.19 The illustration of distinguishing conduct of LBDP, LBPDAP, LBDISP, LBPANDP, and NSST-LBNDP features in discriminating interclass and intraclass images belonging to TCIA-CT 111

5.1 Functional block diagram of ZM-NSST-MSLDEP feature based image retrieval framework 114

5.2 Sample example of NSST-MSLDEP computation in two directions . 118

5.3 Example computation of LBP for a 3×3 neighborhood 119

5.4 The retrieval performance comparison in terms of ARP and ARR for NEMA-CT 122

5.5 The retrieval performance comparison in terms of ARP and ARR for TCIA-CT 123

5.6 The retrieval performance comparison in terms of ARP and ARR for YORK-MRI 124

5.7 Visual retrieval results (row-wise) for LDEP, LWP, LBDP, LBDISP, LBPDAP, CSLBCoP, Cont.-TrP, LDMaMEP, LDEBP and ZM-NSST-MSLDEP descriptors, for the top 12 image matches for NEMA-CT database for a given query image. (The image enclosed inside black color rectangle is a query image. The images enclosed inside green rectangles are correctly retrieved and the images enclosed inside red rectangles are retrieved incorrectly) 126

5.8 Discriminating nature of LBDP,LBPDAP,LDMaMEP,Cont.-TrP and NSST-MSLDEP features of intra class and inter class images of TCIA-CT dataset (a) and (b) are images from same class of TCIA-CT dataset,(c) Image from different class other than (a) and (b),(d) and (e) are the pd w.r.t zero mean of difference between features from intra class and inter class images respectively 127

5.9 Block diagram of ZM-NSST-SVDw descriptor in an image retrieval framework 129

5.10 Log histograms for three detail NSST subbands for five different images of TCIA-CT dataset and the generalized Gaussian, Exponential and Weibull distribution fitted to these histograms. 132

5.11 The retrieval performance comparison in terms of (a)ARP and (b)ARR for NEMA-CT 135

5.12 The retrieval performance comparison in terms of (a)ARP and (b)ARR for TCIA-CT 136

5.13 The retrieval performance comparison in terms of (a)ARP and (b)ARR for YORK-MRI 137

5.14 Visual retrieval results for LDEP, LWP, LBDP, LBDISP, LBP-DAP, CSLBCoP, Cont.-TrP, LDMaMEP, LDEBP, NSST-LBNDP and ZM-NSST-SVDw descriptors (from top most row to last row), for the top 15 image matches for NEMA-CT database for a given query image. (The leftmost image is a query image, while the images inside red boxes were retrieved incorrectly) 139

5.15 Discriminating nature of LBDP,LBPDAP,LDMaMEP,Cont.-TrP, NSST-LBNDP and Proposed features of intra class and inter class images of TCIA-CT dataset (a) and (b) are images from same class of TCIA-CT dataset,(c) Image from different class other than (a) and (b),(d) and (e) are the probability distribution w.r.t zero mean of difference between features from intra class and inter class images respectively 140

5.16 The retrieval performance comparison of NSST-LBPDAP, NSST-LBNDP, ZM-NSST-MSLDEP and ZM-NSST-SVDw in terms of ARP and ARR for (a)NEMA-CT, (b)TCIA-CT, (c)YORK-MRI . . 141

List of Tables

1.1 Types of texture features 10

3.1 Average KS statistics for a few RS images 48

3.2 Databases used in the experiments 50

3.3 Retrieval performance comparison of ANMRR and MAP in WHU-RS19 56

3.4 Retrieval performance comparison for AID and PatternNet datasets in terms of ANMRR and MAP 56

3.5 Comparison of total retrieval time (in seconds) of the NSST-SNIG with other techniques 60

3.6 Average KS test values for a few RS images 65

3.7 Retrieval performance comparison of NSSTds-3DLTP with other schemes for WHU-RS19 73

3.8 Retrieval performance comparison of NSSTds-3DLTP with other schemes for AID and PatternNet 73

3.9 Comparison of feature dimensions of various techniques 76

3.10 Total retrieval time (in seconds) comparison of the NSST-SNIG with other techniques 78

4.1 Details about datasets considered 90

4.2 Evaluation of the NSST-LBPDAP descriptor against other approaches for the NEMA-CT dataset, comparing their % ARP and % ARR values (Top 30 match) 93

4.3 Evaluation of the NSST-LBPDAP descriptor against other approaches for the TCIA-CT dataset, comparing their % ARP and % ARR values (Top 30 match) 93

4.4 Evaluation of the NSST-LBPDAP descriptor against other approaches for the YORK-MRI dataset, comparing their % ARP and % ARR values (Top 100 match) 95

4.5 Evaluation of the NSST-LBPDAP descriptor against other approaches for YORK-MRI dataset (top match 100) for various NSST decomposition levels and directions in terms of % ARP and % ARR 96

4.6 Comparison of feature descriptor size of NSST-LBPDAP with other descriptors 96

4.7 Evaluation of the NSST-LBPDAP descriptor against other approaches in terms of total retrieval time (seconds) 97

4.8 Comparative performance evaluation of NSST-LBNDP and other approaches in terms of % ARP and % ARR for the NEMA-CT dataset (Top 30 match) 105

4.9 Comparative performance evaluation of NSST-LBNDP and other approaches in terms of % ARP and % ARR for the TCIA-CT dataset (Top 30 match) 107

4.10 Comparative performance evaluation of NSST-LBNDP and other approaches in terms of % ARP and % ARR for the YORK-MRI dataset(Top 100 match) 107

4.11 Comparative performance evaluation of NSST-LBNDP for the YORK-MRI dataset (top match 100) using % ARP and % ARR for various NSST decomposition levels and directions. 108

4.12 Comparison of feature descriptor size of the NSST-LBNDP with other techniques 108

4.13 Comparative performance evaluation of NSST-LBNDP and other approaches in terms of total retrieval time (in seconds) 109

5.1 The list of $ZM_{\rho\kappa_z}$ for order ρ_{max}=5 117

5.2 Comparative performance evaluation of ZM-NSST-MSLDEP and other approaches in terms of % ARP and % ARR for NEMA-CT dataset(Top 40 match) 122

5.3 Comparative performance evaluation of ZM-NSST-MSLDEP and other approaches in terms of % ARP and % ARR for TCIA-CT dataset (Top 30 match) 123

5.4 Comparative performance evaluation of ZM-NSST-MSLDEP and other approaches in terms of % ARP and % ARR for YORK-MRI dataset (Top 100 match) 124

5.5 Performance analysis of ZM-NSST-MSLDEP for NEMA-CT dataset (top match 40) in terms of ARP and ARR for different levels of NSST decomposition and directions 125

5.6 Feature dimension comparison of the proposed descriptor with other techniques 125

5.7 Comparative performance evaluation of ZM-NSST-MSLDEP and other approaches in terms of total retrieval time (in seconds) 125

5.8 The estimated parameters of fitted models of the singular values of NSST subband coefficients (2,2 NSST decomposition) for an image from TCIA-CT dataset 131

5.9 Comparative performance evaluation of ZM-NSST-SVDw and other approaches in terms of % ARP and % ARR for NEMA-CT dataset(Top 40 match) 135

5.10 Comparative performance evaluation of ZM-NSST-SVDw and other approaches in terms of % ARP and % ARR for TCIA-CT dataset (Top 30 match) 136

5.11 Comparative performance evaluation of ZM-NSST-SVDw and other approaches in terms of % ARP and % ARR for YORK-MRI dataset (Top 100 match) 137

5.12 Feature dimension comparison of the proposed descriptor with other techniques 138

5.13 Comparative performance evaluation of ZM-NSST-SVDw and other approaches in terms of total retrieval time (in seconds) 138

5.14 Feature dimension and total retrieval time (in seconds) comparison of all the proposed biomedical image feature descriptors 142

List of Acronyms

AID	Aerial image dataset
ANMRR	Average normalized modified retrieval rank
ARP	Average retrieval precision
ARR	Average retrieval recall
BKF	Bessel K form
BoF	Bag of filters
BoT	Bag of Texton
BoVW	Bag of visual words
BoW	Bag of words
CT	Computed Tomography
CBIR	Content Based Image Retrieval
CSLBCoP	Centre symmetric local binary co-occurrence pattern
CLBP	Completed LBP
CDLQP	Color directional local quinary pattern
CLM	Codebook less model
Cont.-TrP	Contourlet tetra pattern
CDF	Cumulative distribution function
DoG	Difference of Gaussian
DWT	Discrete wavelet transform
DTCWT	Dual tree complex wavelet transform
DT-RCWF	Dual tree rotated complex wavelet filter
ECDF	Empirical CDF
EGTD	Enhanced Gabor texture descriptor
EM	Expectation Maximization
EMLBP	Extended multi structure LBP
ELBP	Extended LBP
FD	Feature dimension
FDLBP	Frequency decoded LBP
FV	Fisher Vector
GGD	Generalized Gaussian density

GLCM	Gray level co-occurrence Matrix
GLRLM	Gray level run length Matrix
GG	Generalized Gaussian
HSV	Hue Saturation Value
HOG	Histogram of Oriented Gradients
KLD	Kullback Leibler distance
KS	Kolmogorv-Smirnov
LBP	Local Binary Pattern
LBP^{u2}	Uniform LBP
LBP^{riu2}	Rotation Invariant Uniform LBP
LBPDAP	Local bit-plance dissimilarity adder Pattern
LBNDP	Local bit-plane Neighbor dissimilarity Pattern
LBP-TOP-LBP	LBP in three orthogonal planes
LBDP	Local bit plane decoded pattern
LBDISP	Local bit plane dissimilarity pattern
LBPANDP	Local bit plane adjacent neighborhood dissimilarity pattern
LDEP	Local diagonal extrema pattern
LDEBP	Local directional edge binary pattern
LDN	Local Directional Number Pattern
LDZP	Local directional zigzag pattern
LDRP	Local directional relation pattern
LDMaMEP	Local directional mask maximum edge pattern
LEDP	Local eight directiona pattern
LEP	Local Energy Pattern
LETRIST	Locally Encoded Tranform Feature Histogram
LGHP	Local gradient hexa pattern
LM	Laplacian Mixture
LMeP	Local Mesh Pattern
LMePVEP	Local Mesh Peak Valley Edge Pattern
LNFND	Local neighborhood based wavelet feature descriptor
LNIP	Local neighborhood intensity pattern
LoG	Laplacian of Gaussian
LSEGP	Local shearlet energy gammodian binary pattern
LTP-HF	Local ternary pattern histogram Fourier
LTP	Local ternary Pattern
LTrP	Local tetra Pattern
LTCoP	Local Ternary Co-occurrence Pattern
LTriDP	Local tri-directional pattern

LWP	Local wavelet pattern
MAP	Mean average precision
MDLBP	Multichannel decoded LBP
MEPP	Maximum edge position pattern
ML	Maximum Likelihood
MoGG	Mixture of generalized Gaussian
MRELBP	Median robust extended LBP
MRI	Magnetic Resonace Imaging
MRP	Maximum edge pattern
MSLDEP	Maximum of subbands local directional edge pattern
NEMA	National Electrical Manufacturers Association
NSLP	Non subsampled laplacian pyramid filters
NSST	Non-subsampled Shearlet Transform
OFMM	Orthogonal Fourier Meline moments
PCA	Principal component analysis
P-R curve	Precision-recall curve
PriCoLBP	Pairwise Rotation invariant co-occurrence LBP
RGB	Red Green Blue
RHE-DCT	Regularized histogram equalization and discrete cosine transform
RS	Remote Sensing
RSIR	Remore sensing image retrieval
SIFT	Scale Invariant Feature Transform
SNIG	Symmetric Normal Inverse Gaussian
SVD	Singular Value Decomposition
SURF	Speeded Up Robust Features
TCIA	The cancer imaging archive
THFB	Triplet half band filter bank
VLAD	Vector of Locally Aggregated Descriptors
WC	Wrapped Cauchy
ZM	Zernike Moment
3D-LTP	Three dimensional local ternary Pattern
3D-LBP	Three dimensional LBP

List of symbols

$ST(.)$	Shearlet transform
λ	Scale
ω_o	Orientation
τ	Location parameter
A_λ	Anisotropic dilation matrix
S_{ω_o}	Shear transformation matrix
$\hat{\psi}(.)$	Classical shearlet ψ
I	Image
$NSLP_{p+1}I$	Detail coefficient at scale $p+1$
Ph_q^0	Low pass filters used in NSLP at scale p
Ph_p^1	High pass filters used in NSLP at scale q
$N(\mu_m, \sigma^2)$	Normal distribution with variance σ^2 and mean μ_m
$I_G(\kappa, \delta)$	Inverse Gaussian distribution with parameters κ and δ
δ	Scaling parameter
$f_{IG}(y)$	Probability density function of IG
$SNIG(\alpha, \beta, \mu_m, \delta)$	Symmetric normal inverse Gaussian distribution with α, β, μ_m, δ parameters
$h(c; \alpha, \beta, \mu_m, \delta)$	Probability density function of SNIG
$K_b(c)$	3^{rd} kind modified Bessel function of order b
φ	Set of SNIG parameters
φ^k	Values of parameters after k^{th} iteration
$F(c)$	Model CDF
$\tilde{F}(c)$	Empirical CDF
μ_A	Mean extracted from NSST approximation subband A
σ_A	Standard deviation extracted from NSST approximation subband A

q_1	Query image
$Gr(q_1)$	Size of ground truth
$Ar(q_1)$	Average rank for q_1
N_Q	Total number of query image
$Pr_{ave}(q_1)$	Average precision for each query q_1
$Pr(k)$	Precision at k
$rel(k)$	It is a function that outputs 1 if the item at k^{th} rank is valid else 0
$D(I_q, DB_k)$	Distance between query image I_q and database's k^{th} image
F_l	Feature vector length
$F_{DB_{kj}}$	The j^{th} feature of k^{th} image of database
$F_{I_{qj}}$	The j^{th} feature of query image I_q
$P_{x(j)}(x(j))$	2-state LM model for modelling the image NSST detail coefficients at x(j)
$P_1(.)$and $P_2(.)$	Two non negative functions
w_j	Weights to $P_1(.)$
$1 - w_j$	Weights to $P_2(.)$
$\sigma_1(j)$	Standard deviation of $P_1(.)$
$\sigma_2(j)$	Standard deviation of $P_2(.)$
$r_1(j)$	Responsibility element
$N_m(j)$	Square shaped local window with N_m coefficients inside it
s	skewness
k	kurtosis
$I(P_c)$	Centre pixel value
$I(P_i)$	Neighboring pixel
T	Total number of neighbors
R	Neighborhood radius
F_1	Feature vector
F_2	Feature vector
FV	Final feature vector
$E_L(i,j)$	Local energy over a 3×3 neighborhood at each reference (i,j)
$x(i,j)$	Image NSST coefficients at a reference position (i,j)
$BB_b(i,j)$	Binary bit of $E_L(i,j)$ in b^{th} bit plane
B	Bit depth
$CN_b^T(i,j)\|_{b\in[0,7],T\in[1,8]}$	Centre-neighbor dissimilarity information

$D_{is}(u, v)$	Dissimilarity relation between u and v
$NN_b^T(i,j)\|_{b\in[0,7],T\in[1,8]}$	Neighbor-neighbor dissimilarity information
$AD^{T,b}(i,j)\|_{b\in[0,7],T\in[1,8]}$	Adder pattern obtained with $CN_b^T(i,j)\|_{b\in[0,7],T\in[1,8]}$ and $NN_b^T(i,j)\|_{b\in[0,7],T\in[1,8]}$
EBB_d^b	Encoded bit plane value
$LBPDAP_d(i,j)$	LBPDAP value calculated for d=[0,1,2]
$H_{LBPDAP_d^{s1}}$	Histogram of LBPDAP submap (s_1) for d=[0,1,2]
$H_{LBPDAP_d^{s2}}$	Histogram of LBPDAP submap (s_2) for d=[0,1,2]
$H_{LBPDAP_d^{s3}}$	Histogram of LBPDAP submap (s_3) for d=[0,1,2]
$H_{LBPDAP_d^{s4}}$	Histogram of LBPDAP submap (s_4) for d=[0,1,2]
$P(I_k)$	Precision for k^{th} query image
$R(I_k)$	Recall for k^{th} query image
TD	Total number of images in the database
EB_b,$b \in [0, 7]$	Encoded bit plane value obtained by dissimilarity information between each neighboring value and adjacent neighbors
$BB_{b,k}^a(i,j)$	Each neighbor (with respect to centre/reference bit $BB_b(i,j)$)
$BB_{b,k}^{a,t}(i,j)$	8 adjacent neighbors
$[D_{b,k}^{a,t}(i,j)]$	Dissimilarity function calculated between $BB_{b,k}^a(i,j)$ and $BB_{b,k}^{a,t}(i,j)$
$\zeta_{b,k}^a(i,j)$	Summing operation to combine the 8 dissimilarity bit $[D_{b,k}^{a,t}(i,j)]$
$EB_{b,k}(i,j)$	Encoded bit plane value after weighing $\zeta_{b,k}^a(i,j)$
$H_{NSST-LBNDP_{k,s_1}^q}$	Histogram of LBNDP submap (Patch s_1)
$H_{NSST-LBNDP_{k,s_2}^q}$	Histogram of LBNDP submap (Patch s_2)
$H_{NSST-LBNDP_{k,s_3}^q}$	Histogram of LBNDP submap (Patch s_3)
$H_{NSST-LBNDP_{k,s_4}^q}$	Histogram of LBNDP submap (Patch s_4)
N_s	Total number of subbands
$NSST - LBNDP_k^q(i,j)$	Quantized NSST-LBNDP value calculated for $k \in [1, N_s]$

$ZM_{\rho\kappa_z}$	ZM over a unit disk of order ρ and repetition κ_z
$V_{\rho\kappa_z}(p,q)$	Zernike orthogonal basis function
$V^*_{\rho\kappa_z}(p,q)$	Complex conjugate of $V_{\rho\kappa_z}(p,q)$
$R_{\rho\kappa_z}$	Radial polynomial
p_t	Normalized coordinate pertaining to location (t,u)
q_u	Normalized coordinate pertaining to location (t,u)
ρ_{max}	Maximum order
T_c	Total number of ZM or order ρ_{max}
s	Scale
L	Level of NSST decomposition
θ	Direction
$\xi^{R+1}_{\theta,s,n}$	Normalized energy values at radius $R+1$
$\xi_{\theta,s,n}$	Normalized energy values at radius R
$D_{\theta,s,n}$	Edge information with respect to each reference/centre in a given direction θ, scale s and n^{th} subband
$M_i(x,y)$	Maximum to minimum subband edge distribution
$max^i(p)$	i^{th} maximum location in p array
$NSST-MSLDEP^{\theta,s}(x,y)$	NSST-MSLDEP maps computed in scale s and in θ direction
$H_{NSST-MSLDEP^{\theta,s}}(l)$	Histogram of $NSST-MSLDEP^{\theta,s}$ in a given direction θ and scale s
F_z	Features obtained through lower order ZM of an image
I_s	SVD applied on image I
U	Orthogonal matrix of size $M \times M$
V	Orthogonal matrix of size $N \times N$
S	Diagonal matrix
$\sigma_{s1}, ...\sigma_{sn}$	Singular values for the decomposition
$F(r)$	Weibull distribution for random variable
$\nu > 0$	shape parameter
$\eta > 0$	scale parameter