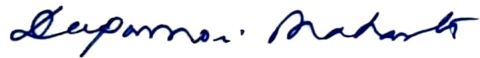


Dedicated to my family and well wishers

Declaration

I do hereby declare that the thesis entitled “**Handcrafted and Deep Features for Biomedical Image Retrieval and Classification Applications**” 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.



(Deepamoni Mahanta)

Date: 19/2/2025

Place: Tezpur, Assam, India



Tezpur University

Department of Electronics and Communication Engineering

Dr. Deepika Hazarika
(Associate Professor)

Phone: 03712-275261
E-Mail: deepika@tezu.ernet.in

Certificate of the Supervisor

This is to certify that the thesis entitled "**Handcrafted and Deep Features for Biomedical Image Retrieval and Classification Applications**" 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. Deepamoni Mahanta 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.


(Dr. Deepika Hazarika)

Associate Professor, Department of Electronics and Communication Engineering
School of Engineering, Tezpur University
Assam, India

Date: 19/3/2025

Place: Tezpur, Assam, India

Declaration

I do hereby declare that the thesis entitled “**Handcrafted and Deep Features for Biomedical Image Retrieval and Classification Applications**” 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.

(Deepamoni Mahanta)

Date:

Place: Tezpur, Assam, India



Tezpur University

Department of Electronics and Communication Engineering

Dr. Deepika Hazarika
(Associate Professor)

Phone: 03712-275261
E-Mail: deepika@tezu.ernet.in

Certificate of the Supervisor

This is to certify that the thesis entitled “**Handcrafted and Deep Features for Biomedical Image Retrieval and Classification Applications**” 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. Deepamoni Mahanta 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.

(Dr. Deepika Hazarika)
Associate Professor, Department of Electronics and Communication Engineering
School of Engineering, Tezpur University
Assam, India

Date:
Place: Tezpur, Assam, India



Tezpur University

Department of Electronics and Communication Engineering

Certificate of External Examiner

The examiners of Oral Defence Evaluation Committee (ODEC) certify that the thesis entitled “**Handcrafted and Deep Features for Biomedical Image Retrieval and Classification Applications**” submitted by Deepamoni Mahanta, 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.

Supervisor
(Dr. Deepika Hazarika)

External Examiner
(.....)

Date:

Place: Tezpur, Assam, India

Acknowledgment

This thesis is a product of my aspirations and the encouragement and support offered by a lot of people. I would like to take this opportunity to thank everyone who has, in one way or another contributed to the fulfilment of this thesis.

To begin with, I would like to thank my supervisor Dr. Deepika Hazarika, Department of Electronics and Communication Engineering, Tezpur University. I am forever grateful to her for her constant support, profound knowledge and understanding that has served as an inspiration for me to pursue my research in the field of Digital Image Processing. For her untiring effort and mental and emotional support during difficult times, I bow down to her in utter reverence. I would also like to express my deep gratitude to Prof. Vijay Kumar Nath, Department of Electronics and Communication Engineering, Tezpur University for his effort and substantial contribution that has made the completion of this thesis possible. Completion of my research would not have been possible without his guidance and insights.

I want to express my gratitude to Prof. Shambhu Nath Singh, the honorable Vice Chancellor of Tezpur University, and Prof. V.K. Jain, the honorable former Vice Chancellor of Tezpur University, for giving me the opportunity to carry out my research.

I want to express my sincere gratitude to our Head of Department Prof. Bhabesh Deka, former Head of Department Prof. Santanu Sharma, Dean school of engineering Prof. Partha Pratim Sahu, and my Doctoral Committee members Prof. Soumik Roy and Dr. Ratul Kumar Baruah, for their continuous encouragement and inspiration. I would like to express my heartfelt gratitude to former nodal officer of AICTE NDF scheme, TU Dr. Nabin Sarmah, TU AICTE cell and AICTE National doctoral fellowship scheme for the support provided for the fulfilment of my research work.

I would like to express my sincere thanks to all the Research Scholars,

teaching and non-teaching members of Department of Electronics and Communication Engineering, who have supported me at all stages during this period. I am grateful for the kindness shown to me. I want to thank present and past members of Visual Computing and Image Processing laboratory and Statistical Visual Computing laboratory, who have helped and supported me during my research work. I am thankful to Dr. Hilly Gohain Baruah, Dr. Rakcinpha Hatibaruah, Mr. Sunil Kumar, Ms. Madhusmita Chakraborty, Mr. Nabojwal Acharjee, Mr. Bhargav Deka, Ms. Pompy R Gogoi, Mr. Bhaskar Jyoti Barman and Mr. Maharshi Kalita.

I would like to take this opportunity to express my profound gratitude to my family, friends and all the well-wishers. I want to thank my father Khagen Chandra Mahanta, mother Narmada Choudhury, aunt Usha Talukdar, brother Kuldeep Mahanta, and nephew Vishal Deka for their invaluable support and encouragement that gave me inspiration and courage to pursue my research. This thesis would not have been possible without their constant motivation. For this, I am forever grateful to them. I would also like to thank my friends Ruhismita Borah, Anjana Saikia and Saquib Ali Ahmed for the constant moral support, motivation, and encouragement, that have helped me stay positive and motivated during the entire phase of my research. Above all, I am immensely grateful to the Almighty God for showering his blessings and giving me the strength to tackle any obstacle on my path.

(Deepamoni Mahanta), Place: Tezpur, Assam, India

List of Figures

1.1	Block diagram of the CBIR framework	4
3.1	Schematic representation of the suggested MS-LBASP feature extraction framework	37
3.2	Bit planes of an image	38
3.3	(a) Local arbitrary sampling structure 1 (LASS1) (b) Sampling order for LASS1 (c) Weights for LASS1 (d) Local arbitrary sampling structure 2 (LASS2) (e) Sampling order for LASS2 (f) Weights for LASS2 (g) Local arbitrary sampling structure 3 (LASS3) (h) Sampling order for LASS3 (i) Weights for LASS3 (j) Local circular sampling structure (LCSS) (k) Sampling order for LCSS (l) Weights for LCSS	39
3.4	Sample calculation of $MS - LBASP_S$ and $MS - LBASP_M$ (a) Sample image (b) Local BPs corresponding to the sample image (c) Local BP encoding with LASS1, LASS2, LASS3 and LCSS with mean fusion for each BP (d) Computation of relationship between fused local BP encoded values and intensity of center-pixel using sign information (e) Computation of relationship between fused local BP encoded values and intensity of center-pixel using magnitude information	40
3.5	Example images from every category of NEMA-CT dataset	43
3.6	Example images from every category of TCIA-CT dataset	43
3.7	Example images from every category of York-MRI dataset	44

3.8	Comparison of MS-LBASP with other methods (a) ARP for NEMA-CT (b) ARR for NEMA-CT (c) ARP for TCIA-CT (d) ARR for TCIA-CT (e) ARP for York-MRI (f) ARR for York-MRI	47
3.9	The $LB - 3D - OACSP$ based feature extraction framework (P1: Construction of 3D cube employing Gaussian filter banks, P2: BP decomposition of respective FI_1, FI_2, FI_3 planes, P3: Inter-scale BPs encoding employing 3-D arbitrary and 3D circular scanning structures i.e. computation of $3DAP_k^{b,m}$ and $3DCP_k^b$, P4: Computation of $3DAFP^{b,m}$ and $3DCFP^{b,m}$ by fusing all its respective pattern maps corresponding to different values of $k \in [0^\circ, 45^\circ, 90^\circ, 135^\circ]$, P5: Combine the three pattern maps of $3DAFP^{b,m}$ corresponding to $m \in [1, 2, 3]$ and the $3DCFP^b$ into one pattern map i.e. $3DACFP^b$ using mean based fusion, P6: Computation of $LB - 3D - OACSP$ by calculating the relationship between $3DACFP^b$ values for different $b \in [7, 6, 5, 4, 3, 2, 1, 0]$ and the centre-pixel intensity, P7: Construction of final feature vector from $LB - 3D - OACSP$)	51
3.10	The 3D arbitrary and 3D circular shaped scanning patterns considered in $LB - 3D - OACSP$ (a) $AP_{0^\circ}^{b,1}$ (b) $AP_{45^\circ}^{b,1}$ (c) $AP_{90^\circ}^{b,1}$ (d) $AP_{135^\circ}^{b,1}$ (e) $AP_{0^\circ}^{b,2}$ (f) $AP_{45^\circ}^{b,2}$ (g) $AP_{90^\circ}^{b,2}$ (h) $AP_{135^\circ}^{b,2}$ (i) $AP_{0^\circ}^{b,3}$ (j) $AP_{45^\circ}^{b,3}$ (k) $AP_{90^\circ}^{b,3}$ (l) $AP_{135^\circ}^{b,3}$ (m) $CP_{0^\circ}^b$ (n) $CP_{45^\circ}^b$ (o) $CP_{90^\circ}^b$ (p) $CP_{135^\circ}^b$	56
3.11	Computation of $LB - 3D - OACSP$ for a given sample image (a) Sample image and three multi-scale Gaussian filtered images (FI_1, FI_2, FI_3) (b) Local BP decomposition of FI_1 plane (c) Local BP decomposition of FI_2 plane (d) Local BP decomposition of FI_3 plane (e) Computation of $3DAP_k^{b,m}$ and $3DCP_k^b$ (f) Computation of $3DACFP^b$ using $3DAFP^{b,m}$ and $3DCFP^b$ and (g) Computation of $LB - 3D - OACSP$ by calculating the relationship between $3DACFP^b$ values for different $b \in [7, 6, 5, 4, 3, 2, 1, 0]$ and the centre-pixel intensity	59
3.12	% Av. precision and recall results of various descriptors including LB-3D-OACSP (a-b) for NEMA-CT (c-d) for TCIA-CT (e-f) for York-MRI	65

3.13	Discriminative behaviour of LB-3D-OACSP, 3D-LTCoP, SS-3D-LTP, LBPANDP, MS-LBASP and 3D-LOZFP feature vectors in pointing out inter-class and intra-class categories from NEMA-CT database. (a) Image 1 (b) Image 2 (c) Image 3 (Image 1 and Image 2 pertains to same category but Image 1 and Image 3 belongs to two different categories.) (d)The probability distribution of feature vector difference corresponding to Image 1 - Image 2 for different descriptors (intra-class) (e) The probability distribution of feature vector difference corresponding to Image 1 - Image 3 for different descriptors (inter-class)	66
3.14	Retrieved images (9 top-matches) for a given query image from NEMA-CT dataset. Images with yellow, green and a red frame denotes query, correct and wrongly retrieved images respectively. . .	67
4.1	Block diagram of the proposed framework	74
4.2	Schematic representation of Inception-v3 structure [1]	78
4.3	Schematic representation of VGG-19 structure [2]	80
4.4	Transfer learning process	81
4.5	Sample images from each category of the datasets 1, 2, and 3 (left: COVID-19, middle: Normal, right: Pneumonia)	84
4.6	Confusion matrix of 3-class classification on dataset 1 using (a) Blended Inception-v3 and VGG-19 , (b)Inception-v3, (c)VGG-19 . .	87
4.7	ROC of the proposed framework on dataset 1 (a) Blended Inception-v3 and VGG-19, (b)Inception-v3, (c)VGG-19	88
4.8	Confusion matrix of 3-class classification on dataset 2 using (a) Blended Inception-v3 and VGG-19 , (b)Inception-v3, (c)VGG-19 . .	89
4.9	ROC of the proposed framework on dataset 2 (a) Blended Inception-v3 and VGG-19, (b)Inception-v3, (c)VGG-19	89
4.10	Confusion matrix of 3-class classification on dataset 3 using (a) Blended Inception-v3 and VGG-19 , (b)Inception-v3, (c)VGG-19 . .	90

4.11	ROC of the proposed framework on dataset 3 (a) Blended Inception-v3 and VGG-19, (b)Inception-v3, (c)VGG-19	91
4.12	Block representation of the suggested structure	94
4.13	Distribution of neighbors	97
4.14	Flowchart for the bitplane based pattern image formation	99
4.15	Schematic representation of DenseNet structure [3]	100
4.16	ROC pertaining to the suggested framework for (a) Dataset-1, (b) Partially zoomed version of (a)	103
4.17	ROC pertaining to the suggested framework for (a) Dataset-2, (b) Partially zoomed version of (a)	104
4.18	ROC pertaining to the suggested framework for (a) Dataset-3, (b) Partially zoomed version of (a)	105
4.19	ROC pertaining to the suggested framework for (a) combined Dataset (b) Partially zoomed version of (a)	107
4.20	Confusion matrix of 3-class classification of the proposed method on (a) Dataset 1 (b) Dataset 2 (c) Dataset 3 (d) Combined Dataset	108
5.1	Block diagram of the proposed framework	115
5.2	Pictorial representation of CycleGAN	116
5.3	Layer architecture (a) DarkNet-53 (b) Modified DarkNet-53	121
5.4	Layer architecture (a) ResNet-50 (b) Modified ResNet-50	122
5.5	Layer architecture (a) MobileNet-v2 (b) Modified MobileNet-v2 . .	123
5.6	Representative images from ISIC 2018 dataset	124
5.7	Representative images from ISIC 2019 dataset	124
5.8	Confusion matrix for ISIC 2018 (a) Using fine-tuned original DarkNet-53 model (b) Using modified DarkNet-53 model	127

5.9	Confusion matrix for ISIC 2018 (a) Using fine-tuned original ResNet-50 (b) Using modified ResNet-50 model	128
5.10	Confusion matrix for ISIC 2018 (a) Using fine-tuned original MobileNet-v2 model (b) Using modified MobileNet-v2 model	128
5.11	Confusion matrix for proposed ensemble model that combines original DarkNet-53, ResNet-50, MobileNet-v2 models and proposed modified DarkNet-53, ResNet-50, and MobileNet-v2 models	128
5.12	ROC plot for ISIC 2018 (a) Using fine-tuned original DarkNet-53 model (b) Using modified DarkNet-53 model	129
5.13	ROC plot for ISIC 2018 (a) Using fine-tuned original ResNet-50 (b) Using modified ResNet-50 model	129
5.14	ROC plot for ISIC 2018 (a) Using fine-tuned original MobileNet-v2 model (b) Using modified MobileNet-v2 model	129
5.15	ROC plot for proposed ensemble model for ISIC 2018	130
5.16	Confusion matrix for ISIC 2019 (a) Using fine-tuned original DarkNet-53 model (b) Using modified DarkNet-53 model	131
5.17	Confusion matrix for ISIC 2019 (a) Using fine-tuned original ResNet-50 (b) Using modified ResNet-50 model	132
5.18	Confusion matrix for ISIC 2019 (a) Using fine-tuned original MobileNet-v2 (b) Using modified MobileNet-v2 model	132
5.19	Confusion matrix for proposed ensemble model for ISIC 2019	132
5.20	ROC plot for ISIC 2019 (a) Using fine-tuned original DarkNet-53 model (b) Using modified DarkNet-53 model	133
5.21	ROC plot for ISIC 2019 (a) Using fine-tuned original ResNet-50 (b) Using modified ResNet-50 model	133
5.22	ROC plot for ISIC 2019 (a) Using fine-tuned original MobileNet-v2 (b) Using modified MobileNet-v2 model	133
5.23	ROC plot for proposed ensemble model for ISIC 2019	135

List of Tables

3.1	Details about dataset used	44
3.2	%ARP and %ARR comparison of various methods over NEMA-CT(40 top matches) , TCIA-CT (70 top matches) and York-MRI (100 top matches). The % performance improvement of MS-LBASP over a given method is shown in parentheses.	46
3.3	% ARP comparison of MS-LBASP with an implementation of LBDP which uses zigzag sampling	49
3.4	%ARP and %ARR results for LB-3D-OACSP and different existing descriptors for three biomedical image datasets. The % performance improvement of LB-3D-OACSP over a given method is shown in parenthesis	64
3.5	Total retrieval time (in seconds) and feature dimension comparison of LB-3D-OACSP and other descriptors	68
4.1	Proposed structure of GAN and its hyperparameters	77
4.2	Selected hyper parameters used for training	82
4.3	Details of the Curated dataset for CXR images	83
4.4	Radiology dataset attributes	83
4.5	Dataset 3 attributes	83
4.6	Performance evaluation of various models on dataset 1 for COVID-19 detection	87

4.7	Performance evaluation of various models on dataset 2 for COVID-19 detection	89
4.8	Performance evaluation of various models on dataset 3 for COVID-19 detection	90
4.9	Comparison of accuracy of the proposed method with existing techniques using CXR images for COVID-19 detection	91
4.10	Accuracy comparison of different architectures without or with (GAN/ affine) augmentation for dataset-1 for COVID-19 detection .	92
4.11	Chosen hyper parameters that were employed during training . . .	101
4.12	Performance evaluation of various networks on Dataset 1	102
4.13	Performance evaluation of various networks on Dataset 2	104
4.14	Performance evaluation of various networks on Dataset 3	105
4.15	Performance evaluation of various networks on Combined Dataset .	106
4.16	Comparative analysis of accuracy of the proposed framework with existing methods	107
5.1	Description of ISIC 2018 and ISIC 2019 datasets	125
5.2	Comparison of proposed framework with original fine tuned and proposed modified DL models w.r.t various parameters for ISIC 2018 dataset	127
5.3	Comparison of proposed framework with original fine tuned and proposed modified DL models w.r.t various parameters for ISIC 2019 dataset	131
5.4	Comparison of accuracy between augmented and non augmented datasets	134
5.5	Comparison of proposed framework with a few state of the art techniques on ISIC 2018 and ISIC 2019 datasets	134

List of Acronyms

AI	Artificial intelligence
ARP	Average retrieval precision
ARR	Average retrieval recall
ACO	Ant colony optimisation
AUC	Area under the curve
BoW	Bag of words
BP	Bit-Plane
CT	Computed tomography
CXR	Chest X-ray
CAD	Computer-aided diagnosis
COVID-19	Coronavirus disease 2019
CBIR	Content based image retrieval
CNN	Convolutional neural network
CLAHE	Contrast-limited adaptive histogram equalization
CSLBCoP	Centre symmetric local binary co-occurrence pattern
CLBP	Completed LBP
CSLBP	Centre-symmetric LBP
CFS	Correlation-based feature selection
DL	Deep learning
DCNN	Deep convolutional neural network
FC	Fully connected
FP	False positive
FPR	False positive rate
FN	False negative
FS	Feature selection
GAN	Generative adversarial network
GLCM	Gray level co-occurrence matrix
GAP	Global average pooling
HOG	Histogram of oriented gradients
ISIC	International skin imaging collaboration

LBP	Local binary pattern
LBPDAP	Local bit plane-based dissimilarities and adder pattern
LANet	Long attention network
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
LDP	Local derivative pattern
LDZP	Local directional zigzag pattern
LMeP	Local mesh pattern
LMePVEP	Local mesh peak valley edge pattern
LoG	Laplacian of gaussian
LB-3D-OACSP	Local bit-plane domain 3D oriented arbitrary and circular shaped scanning pattern
LSTM	Long short term memory
LTP	Local ternary pattern
LTCoP	Local ternary co-occurrence pattern
LWP	Local wavelet pattern
LZMHPP	Local zigzag max histograms of pooling pattern
ML	Machine learning
MLP	Multilayer perceptron
MRI	Magnetic resonance imaging
MS-LBASP	Multiscale local bit plane arbitrary shaped pattern
NEMA	National electrical manufacturers association
NSST	Non-subsampled shearlet transform
NSST-LBNDP	NSST local bit-plane neighbour dissimilarity pattern
PCA	Principal component analysis
PET	Positron emission tomography
RGB	Red Green Blue
RTPCR	Real-time reverse transcription-polymerase chain reaction
ResNet	Residual network
ROC	Receiver operating characteristic
SIFT	Scale invariant feature transform
SMOTE	Synthetic minority oversampling technique
SVM	Support vector machine
SURF	Speeded up robust features
SARS-CoV-2	Severe acute respiratory syndrome corona virus 2

SC	Skin cancer
SL	Skin lesion
SS-3D-LTP	Spherical symmetric three-dimensional LTP
SGDM	Stochastic gradient descent with momentum
TBIR	Text based image retrieval
TL	Transfer learning
TP	True positive
TPR	True positive rate
TN	True negative
TCIA	The cancer imaging archive
VGG	Visual geometry group
WHO	World health organization
YOLO	You only look once
3D-LOZFP	Three dimensional local oriented zigzag fused pattern
3D-LTC _o P	Three dimensional local ternary co-occurrence pattern
3D-LCDP	Three dimensional local circular difference pattern
3D-LCDWP	Three dimensional local circular difference wavelet pattern
3D-LOZTC _o FP	Three dimensional local-oriented zigzag ternary co-occurrence fused pattern

List of Symbols

$I(p, q)$	Image
B_k	Binary bit in k^{th} bit plane
b_d	Bit depth
R	Number of rows
C	Number of columns
t	Neighbour
$\varphi(v)$	Threshold function, equal to 1 if v is greater than or equal to 0, else equal to 0
$E^{p,q,k}$	Local bit-plane encoded value
$MS - LBASP_S^{p,q}$	Sign MSLBASP
$MS - LBASP_M^{p,q}$	Magnitude MSLBASP
Th	Threshold
$MS - LBASP_{S_q}$	Quantized $MS - LBASP_S^{p,q}$
$MS - LBASP_{M_q}$	Quantized $MS - LBASP_M^{p,q}$
Db	Size of dataset
$P(I_j)$	Precision
$R(I_j)$	Recall
F_L	Feature vector length
$D(I_q, Db_k)$	Distance between the query image I_q and the database's k^{th} image
σ_s	Standard deviation ($s \in [1, 2, 3]$)
$G(i, j, \sigma)$	Gaussian filter for standard deviation σ_s
FI_s	Gaussian filtered image
N_R	Number of rows
N_C	Number of columns
m	Unique patterns, $m \in [1, 2, 3]$
b	Bit plane, $b \in [7, 6, 5, 4, 3, 2, 1, 0]$
k	Direction $k \in [0^0, 45^0, 90^0, 135^0]$
AP_k^m	3D arbitrary patterns

CP_k	3D circular patterns
$3DAP_k^{b,m}$	Encoded binary BPs using AP_k^m
$3DCP_k^b$	Encoded binary BPs using CP_k
$3DAFP^{b,m}$	Fused $3DAP_k^{b,m}$ for four different directions
$3DCFP^b$	Fused $3DCP_k^b$ for four different directions
$3DACFP^b$	Combination of all pattern maps
$LB - 3D - OACSP(p, q)$	Local Bit-Plane Domain 3D Oriented Arbitrary and Circular Shaped Scanning Patterns
$\psi(x)$	Threshold function, equal to 1 if x is greater than or equal to 0, else equal to 0
$H_{LB-3D-OACSP^x}(l)$	Histogram of $LB - 3D - OACSP$
$f_m(a, b)$	Threshold function, equal to 1 if $a=b$, else equal to 0
$BI(x, y)$	Image
R_1	Radius 1
R_2	Radius 2
$C_t^k(x, y)$	Dissimilarity between the reference bit and all its neighbouring bits at radius 1
$D_t^k(x, y)$	Dissimilarity between the neighbours at radius 1 and the selected neighbours at radius 2
$\rho(e, f)$	Threshold function, equal to 1 if $e \neq f$, else equal to 0
$\phi(e, f)$	Threshold function, equal to 1 if $e \neq f$, else equal to 0
$DS^k(x, y)$	Dissimilarity between C_t^k and D_t^k
$LBMDP(x, y)$	Local BP multiple dissimilarity pattern
L_{GAN}	Adversarial loss
L_{cyc}	Cycle-consistency loss