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My family and friends

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I certify that

- The work contained in the dissertation is original and has been done by myself under the general supervision of my supervisors.
- The work has not been submitted to any other Institute for any degree or diploma.
- I have followed the guidelines provided by Tezpur University in writing the thesis.
- I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the university.
- Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the dissertation and giving their details in the references.



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Certificate

This is to certify that the thesis entitled “**Convolutional Neural Network Assisted Off-line Handwritten Character Recognition of Meitei Mayek**” submitted to Tezpur University in the Department of Computer Science and Engineering under the School of Engineering in partial fulfillment of the award of the degree of Doctor of Philosophy in Computer Science and Engineering is a record of research work carried out by **Deena Hijam** under my supervision and guidance.

All helps 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

This is to certify that the thesis entitled “**Convolutional Neural Network Assisted Off-line Handwritten Character Recognition of Meitei Mayek**” submitted by **Deena Hijam** to Tezpur University in the Department of Computer Science and Engineering under the School of Engineering in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Computer Science and Engineering has been examined by us on **.14.03.2024..** and found to be satisfactory.

The Committee recommends for award of the degree of Doctor of Philosophy.

Signature of Principal Supervisor

Signature of External Examiner

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Glossary of Terms

HCR	Handwritten Character Recognition
OCR	Optical Character Recognition
NN	Neural Network
HMM	Hidden Markov Model
SVM	Support Vector Machine
KNN	K-Nearest Neighbor
RF	Random Forest
DT	Decision Tree
HOG	Histogram of Oriented Gradients
SIFT	Scale-Invariant Feature Transform
SURF	Speeded Up Robust Features
CNN	Convolutional Neural Network
RNN	Recurrent Neural Network
LSTM	Long Short-Term Memory
LM	Language Model
ILSVRC	ImageNet Large Scale Visual Recognition Challenge
MLP	Multi-Layer Perceptron
LBP	Local Binary Pattern
TUMMHCD	Tezpur University Meitei Mayek Handwritten Character Dataset
CMATER	Center for Microprocessor Application for Training Education and Research
CENPARMI	Centre for Pattern Recognition and Machine Intelligence
DWT	Discrete Wavelet Transform
ORB	Oriented FAST and Rotated BRIEF
IPI	Image Pixel Intensity
ReLU	Rectified Linear Unit
HHR	Handwritten Hangul Recognition
ELU	Exponential Linear Unit

VLAD	Vector of Locally Aggregated Descriptors
ELM	Extreme Learning Machine
TDIL	Technology Development for Indian Languages
TIFF	Tagged Image File Format
BN	Batch Normalization
TL	Transfer Learning
FT	Fine Tuning

Symbols and Notations

$\psi(t)$	Mother wavelet function
$\langle f, \phi_n \rangle$	Inner product of the two functions
C_i	i^{th} convolutional layer
P_i	p^{th} pooling layer
FC_i	i^{th} fully-connected layer
\mathbb{R}	Set of real numbers
ϑ	Validation set of TUMMHCD
T	Test set of TUMMHCD
c_i	Character class with class id i
ϑ_i	Set of images in the validation set belonging to class c_i
α	Initial learning rate
α_i	Learning rate decay after iteration i
$i@j \times j$	i output feature maps of size $j \times j$
Rec_set	Set of second-level recognizers
G	Magnitude of image gradient
θ	Direction of image gradient
V_{in}	L2 normalized vector
$char_i$	i^{th} character in a word
u_i	y co-ordinate of the uppermost pixel of $char_i$
l_i	y co-ordinate of the lowermost pixel of $char_i$