Dedicated to

My family and friends

Declaration

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

Acknowledgment

This PhD dissertation would not have been possible without the help of numerous people, who with their kind cooperation and active support have made this research work a reality. Writing this dissertation has been a memorable journey in which I was accompanied by many. First and foremost, I would like to express my gratitude to my supervisor Prof. Sarat Saharia for the useful comments, remarks and engagement through the learning process of this PhD thesis. He gave me freedom to pursue my ideas and work at my own pace, and was always available to discuss various problems on the way. I acknowledge my indebtedness and deep sense of gratitude to him for his patience, guidance and admirable support throughout the entire process of writing this dissertation.

I would like to extend my deepest gratitude to the anonymous experts for their valuable comments which helped me dive more into my research topic and improve the quality of the thesis.

I am grateful to my parents, my sisters and my brother who continue to be my constant source of inspiration and support behind my endeavors. This PHD thesis wouldn't have been possible without the moral support and encouragement I receive from them. I would like to thank my husband for his motivation and understanding academically and personally which has enabled me to complete my PhD work. I would like to extend my love to my newborn baby for being my motivator in his own way during the last days of writing this dissertation.

I am indebted to the Department of Computer Science and Engineering of Tezpur University and its faculty members from whom I have gained most of my knowledge in my area of research. I would like to acknowledge my sincere gratitude to all the doctoral committee members of my research especially Prof. Utpal Sharma for his valuable comments and suggestions. I extend my sincere thanks to other faculty members with a special mention of Dr. Arindam Karmakar and the non-teaching staff of the Department, for their generous help in various

ways towards the completion of the work.

I would like to express my gratitude to the teachers and students of Dhanamanjuri College of Arts, Manipur Public School, St. Joseph's School, Brighter Academy, Manu English School, Maria Montessori and Comet School for their cooperation and support during the sample collection process. I extend my gratitude to my brothers Jackson Moirangthem and Lamjingkhomba Hijam for helping with the dataset creation. I would like to thank Nirmal da for always being there to clear my doubts in Meitei Mayek.

I consider myself very fortunate to have had the company of some wonderful people who I can call my friends. I would like to thank Carynthia, Piyali, Arundhati, Binayak, Nirmal da and che Margaret and their families who made my stay at Tezpur University very pleasurable. I will always cherish the times spent with them.

Finally, I would like to thank all those who have directly or indirectly helped me in different capacities to complete my research work.

Deena Hijam

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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 $char_i$