IMPLEMENTATION OF DEEP NEURAL NETWORKS ON EMBEDDED SYSTEMS FOR REAL-TIME HAND GESTURE RECOGNITION USING A 24 GHz DOPPLER RADAR

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MSc in Telecommunication

Department of Electronic and Telecommunication Engineering
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DECLARATION

I declare that this is my own work and this Thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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The supervisors should certify the Thesis with the following declaration.

The above candidate has carried out research for the MSc in Telecommunication Thesis under our supervision. We confirm that the declaration made above by the student is true and correct.

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Signature of the Supervisor: Digitally signed by Chamira U. S. Edussooriya Date: 13/06/2025

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Signature of the Supervisor: A.T.L.K. Samarasinghe 2025.06.13 10:22:18 +05'30' 2025.1.0 Date: 13/06/2025

DEDICATION

To everyone who helped us make this project a success.

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ABSTRACT

Real-time hand gesture recognition is a key component of next-generation human-computer interaction, with applications in smart environments, assistive technologies, and contactless control systems. This research uses deep neural networks in embedded systems for radar-based gesture recognition, where the gesture signals are captured using a 24 GHz Doppler radar sensor, and the processing is done in the embedded edge computing resources.

The project uses two types of deep learning models: a vision transformer (ViT) that captures long-range components for superior classification and a deep convolutional neural network (DCNN) that captures local spatial features. This work uses hyperparameter optimization, model pruning, and integer quantization to increase accuracy and efficiency, but with minimal loss, to achieve real-time performance on low-power hardware. Hyperparameter optimization is used to improve model architecture performance. In order to achieve better performance and lower resource consumption, pruning is employed. The integer quantization shrinks the size of the deep learning models for lower-power devices with an increased inference speed.

The proposed system is deployed on an embedded platform while ensuring low latency, reduced power consumption, and real-time inference. The deployment results validate the feasibility of radar-based gesture recognition in embedded devices. The experiments compare the optimized DCNN and ViT models, evaluating their speed, memory usage, accuracy, and energy efficiency. The results highlight the trade-offs between accuracy and efficiency, providing valuable insight into the feasibility of deep learning for real-time radar-based gesture recognition on embedded devices. This research contributes to the advancement in the deployment of deep learning models in embedded devices.

Keywords: Hand Gesture Recognition, Vision Transformers, Deep Convolutional Neural Networks, Deep Learning Model Optimization, Embedded Systems

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
AI	artificial intelligence
BLSTM	bidirectional long short-term memory
CNN	convolutional neural network
CTC	connectionist temporal classification
CW	continuous wave
DCNN	deep convolutional neural network
DL	deep learning
DT	decision tree
FFT	fast fourier transform
FMCW	frequency modulated CW
FPU	floating point unit
HAL	hardware abstraction layer
HCI	human-computer interaction
HGR	hand gesture recognition
HMM	hidden markov model
HMR	human motion recognition
IoT	internet of things
LO	local oscillator
MDS	micro Doppler signatures
MLP	multi-layer perceptron
MSENet	multiscale squeeze-and-excitation network
MViT	multiscale vision transformers
NLP	natural language processing
PTQ	post-training quantization
QAT	quantization-aware training
SFCW	single frequency CW
STFT	short time fourier transform
SVM	support vector machine
TFLite	tensorflow lite
ViT	vision transformer

LIST OF APPENDICES