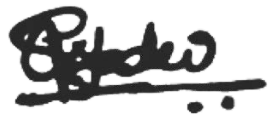
Declaration

I hereby declare that the work presented in this thesis titled *Automatic Modulation Classification using Deep Learning Techniques* submitted to Indian Institute of Technology Jodhpur in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy, is a bonafide record of the research work carried out under the supervision of Dr. Sandeep Kumar Yadav. The contents of this thesis in full or in parts, have not been submitted to, and will not be submitted by me to any other Institute or University in India or abroad for the award of any degree or diploma.

Yogesh Kumar
P15EE202

Certificate

This is to certify that the thesis titled *Automatic Modulation Classification using Deep Learning Techniques*, submitted by *Yogesh Kumar (P15EE202)* to Indian Institute of Technology Jodhpur for the award of the degree of *Doctor of Philosophy*, is a bonafide record of the research work done by him under my supervision. To the best of my knowledge, the contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.



Sandeep Kumar Yadav
Ph.D.Thesis Supervisor

Acknowledgments

I thank my Ph.D. Thesis Supervisor, *Dr. Sandeep Kumar Yadav*, for introducing me to the area of signal processing and communication systems. Within the procedure, I found out many technical and non-technical elements of professional paintings. I am grateful to him for his *assist* and *endurance* as well as for constantly reminding me to be best within the little matters that I do every day.

I thank *Dr. Abhay Samant*, *Mr. Raghunandan* and *Mr. Varun* from National Instruments for introducing me to the hardware of wireless system which helped me to apprehend the ideas in a better way. I thank *Mr. Ashok Kumar*, *Mr. Gaurav Jajoo*, and *Mr. Manu Sheoran* for having fruitful technical discussions on numerous subjects at some stage in my stay at IITJ.

My stay at the Institute become a splendid experience because of my buddies, *Gaurav, Amit, Amrik, Gajendra, Mahmood, Surbhi, Manpreet,* and *Kanika*, for all the liveliness they infused into the non-academic part of the days at IIT Jodhpur...

Finally, I want to thank my spouse, *Anita* from the bottom of my heart for helping me to complete this adventure. She helped by watching our daughter *Navya* after I had to do work on my studies or to be on campus. She has been with me from the begin to the finish of my Ph.D. research and she will enjoy with me the culmination of this labor now that it's complete. I acknowledge and thank my *whole* circle of relatives, for the persistence and love which they ushered on me, and for bearing with me even when I was not spending much less time with them. I pay respects to my *mother and father* for all their *love, sacrifices and blessings*…

List of Figures

List of Tables

List of Symbols

Symbol	*Description*
Δp	Oversampling factor resolution
γ_{max}	Maximum value of the spectral power density of the normalized and centered instantaneous amplitude
σ_{ap}	Standard deviation of the absolute value of the non-linear component of the instantaneous phase
σ_{dp}	Standard deviation of the non-linear component of the direct instantaneous phase
$\mathbb{S}$	Evaluation of the spectrum symmetry around the carrier frequency
σ_{aa}	Standard deviation of the absolute value of the normalized and centerd instantaneous amplitude of the signal samples
σ_{af}	Instantaneous frequency
σ_{a}	Instantaneous amplitude
μ_{42}^{a}	Kurtosis of the normalized and centered instantaneous amplitude
r	Received complex baseband signal
μ_{42}^{f}	Kurtosis of the normalized and centered instantaneous frequency
$R_r^{\alpha}(\tau)$	Cyclic autocorrelation
$S_r(f)$	Spectral correlation function
s	Transmitted complex baseband signal
η	Probability density function of AWGN
ρ	Correlation coefficient
$\Delta\phi$	Phase offset
$\hat{\alpha}$	Fading channel attenuation
$\mathfrak{L}$	Likelihood function
N	Number of symbols
Δf	Carrier frequency offset
$p < . >$	Pulse shaping filter
$\mathfrak{M}$	Modulation set
f_c'	Estimated carrier frequency
f_s	Sampling frequency
OS	Oversampling factor
r_R	Passband received signal
f_c	Carrier frequency
f'	Estimated frequency
R_s	Symbol rate
$\mathscr{L}$	Sample delay in SDP formation
$\mathscr{G}$	Amplification factor in SDP formation
$d(i,j)$	Density of points in $(i,j)^{th}$ grid section
$I(i,j)$	Intensity of $(i,j)^{th}$ pixel
$\mathscr{F}$	Fast Fourier Transform
ε	Constellation error
I_i	Ideal constellation points
M	Modulation order
ΔT	Symbol time offset

List of Abbreviations

Abbreviation	*Full form*
2D-FFT	Two-Dimensional Fast Fourier Transform
ALPLT	Adaptive Local Power Law Transform
ALRT	Average Likelihood Ratio Test
AMC	Automatic Modulation Classification
ANN	Artificial Neural networks
ASK	Amplitude Shift Keying
AWGN	Additive White Gaussian Noise
CDM	Constellation Density Matrix
CF	Carrier Frequency
CFO	Carrier Frequency Offset
CNN	Convolution Neural Network
CR	Cognitive Radio
CSI	Channel State Information
CSV	Comma Separated Values
DCNN	Deep Convolution Neural Network
DFT	Discrete Fourier Transform
DL	Deep Learning
FB	Feature Based
FFT	Fast Fourier Transform
FIFO	First In First Out
FPGA	Field-Programmable Gate Array
FSK	Frequency Shift Keying
GLRT	Generalized Likelihood Ratio Test
GMM	Gaussian Mixture Model
GP-KNN	Genetic Programming- k Nearest Neibour
GPU	Graphics Processing Unit
HLRT	Hybrid Likelihood Ratio Test
HOC	Higher Order Cumulants
IID	Independent and Identically Distributed
K-S	Kolmogorov-Smirnov
LB	Likelihood Based
LO	Local Oscillator
MFCC	Mel-frequency Cepstral Coefficients
ML	Machine Learning
MSE	Mean Square Error
MSK	Minimum Shift Keying
NI	National Instrument
NLP	Natural Language Processing
OP	Optimum Parameters
OS	Over Sampling
PDF	Probability Density Function
PO	Phase Offset
PSK	Phase Shift Keying
PU	Primary User
QAM	Quadrature Amplitude Modulation
ReLU	Rectified Linear Unit
RF	Radio Frequency
RRC	Root Raised Cosine
SCF	Spectral Correlation Function
SD	Standard Deviation

Abbreviation	*Full form*
SDP	Symmetric Dot Pattern
SDR	Software Defined Radio
SNR	Signal to Noise Ratio
SR	Symbol Rate
STO	Symbol Time Offset
SU	Secondary User
SVM	Support Vector Machine
VHDL	Very High Speed Integrated Circuit Hardware Description Language
VI	Virtual Instrument