

**ENHANCED PARTICLE SWARM
OPTIMIZATION-BASED MODELS AND THEIR
APPLICATION TO LICENSE PLATE
RECOGNITION**

HUSSEIN SALEM ALI BIN SAMMA

**UNIVERSITI SAINS MALAYSIA
2016**

**ENHANCED PARTICLE SWARM OPTIMIZATION-BASED
MODELS AND THEIR APPLICATION TO LICENSE PLATE
RECOGNITION**

by

HUSSEIN SALEM ALI BIN SAMMA

**Thesis submitted in fulfillment of the requirement
for the degree of
Doctor of Philosophy**

February 2016

ACKNOWLEDGEMENT

الحمد لله الذي بنعمته تتم الصالحات

Foremost, I would like to express my deepest and sincerest gratitude to God, the most Merciful for letting me through all the difficulties, and for providing me the blessings to complete this research.

It is with immense gratitude that I acknowledge the help of my former supervisor who is my currently co-supervisor, Professor Dr. Chee Peng Lim for the continuous support throughout my study and research, motivation, enthusiasm, knowledge, and his help in editing this thesis is acknowledge. It was a great honour to work under his supervision.

I would like to express my deepest appreciation and thanks to my current main supervisor, Associate Professor Dr. Junita Mohamad Saleh for giving invaluable help, advising support, suggestions, comments, and her effort in checking this thesis is appreciated. I want to express my gratitude also to my former supervisor, Associate Professor Umi Kalthum Ngah for her great assistance, and help to accomplish this research. This work would not have been possible without the generous support of all my supervisors.

I would like to express my deepest appreciation to School of Electrical and Electronics, USM for providing me the necessary facilities, equipment, as well as Graduate Assistant support and the helpful staff who made this research possible.

Last, but not least, this work is specially dedicated to people in my heart; my father, my mother, my beloved wife, my kids, my brothers, and my sisters for their love, unconditional support, continued prayers and for all of the sacrifices that they have made throughout my life. I cannot find words to express my gratitude, respect and appreciation for them.

TABLE OF CONTENTS

Acknowledgment.....	ii
Table of Contents	iv
List of Tables	ix
List of Figures	xii
List of Abbreviations	xviii
Abstrak.....	xx
Abstract	xxii
CHAPTER 1 - INTRODUCTION	
1.1 Background	1
1.2 Pattern Recognition.....	1
1.3 Computational Intelligence Models	4
1.3.1 Particle Swarm Optimization.....	6
1.3.2 Reinforcement Learning	6
1.3.3 Support Vector Machine.....	7
1.4 Vehicle License Plate Recognition Models	7
1.5 Research Motivations and Problems	8
1.6 Research Objectives and Scope	11
1.7 Proposed Research Methodology.....	13
1.8 Thesis Organization	15

CHAPTER 2 - LITERATURE REVIEW

2.1	Background	17
2.2	Particle Swarm Optimization and Its Variants	17
2.2.1	Modified PSO-Based Algorithms	18
2.2.2	Hybrid PSO-Based Algorithms	20
2.2.3	Cooperative PSO-Based Algorithms	22
2.2.4	Micro PSO-Based Algorithms	23
2.2.5	Memetic PSO-Based Algorithms	24
2.3	Vehicle License Plate Recognition Methods	31
2.3.1	Computational Intelligence-Based Techniques	31
2.3.2	Conventional VLPR Methods	37
2.4	Vehicle Plate Characters Classification Methods	41
2.4.1	Computational Intelligence-Based Techniques	42
2.4.2	Template Matching-Based Methods	44
2.5	Summary	46

CHAPTER 3 - A NEW REINFORCEMENT LEARNING-BASED MEMETIC PARTICLE SWARM OPTIMIZER

3.1	Introduction	48
3.2	The PSO Algorithm	49
3.3	Proposed Reinforcement Learning-based Memetic Particle Swarm Optimizer (RLMPSO)	52
3.3.1	Reinforcement Learning	52

3.3.2	The RLMPSO Structure	55
3.3.3	Modeling of the States	57
3.3.4	Q-Table Structure and Contents	58
3.3.5	The Boundary Condition	61
3.3.6	Exploration and Convergence Operations	63
3.3.7	Jump Operation.....	65
3.3.8	Fine-Tuning Operation	66
3.4	Bootstrap Hypothesis Test	69
3.5	Experimental Study	71
3.5.1	Parameter Settings and Performance Metrics.....	71
3.5.2	Case Study I: Unimodal and Multi-Modal Benchmark Problems.....	72
3.5.3	Case Study II: Composite Benchmark Problems	85
3.5.4	Case Study III: A Real-World Benchmark Problem	89
3.6	Discussion	91
3.7	Summary	92
CHAPTER 4 - RLMPSO FUZZY SUPPORT VECTOR MACHINE OBJECT RECOGNITION MODEL		
4.1	Background	94
4.2	Fuzzy SVM and SVM Classifier.....	96
4.3	The Proposed Model	100
4.4	Experimental Studies	106
4.4.1	Performance Measures	110

4.4.2	Analysis of Model Parameters.....	111
4.4.3	Comparison with Other SVM-Based Models.....	117
4.4.4	Comparison with Other Models	120
4.4.5	Comparison with Published Models.....	121
4.5	Summary	122

CHAPTER 5 - A TWO-STAGE OBJECT RECOGNITION MODEL WITH AN ENHANCED RLMP SO MODEL

5.1	Background	124
5.2	The Proposed Two-Stage Model.....	125
5.3	The Enhanced RLMP SO Model	126
5.3.1	Global Optimization Layer	128
5.3.2	Local Optimization Layer.....	129
5.3.3	Component Optimization Layer	131
5.4	Experimental Studies	131
5.4.1	Comparison with the Single-Stage Model.....	132
5.4.2	Comparison with Other CI-based Models	135
5.4.3	Comparison with Other Optimizers.....	136
5.5	Summary	138

CHAPTER 6 - APPLICATION TO VEHICLE LICENSE PLATE RECOGNITION

6.1	Introduction.....	140
6.2	Malaysian Vehicle License Plate Recognition.....	142

6.3	Experimental Studies	149
6.3.1	Evaluation of the Vehicle License Plate Recognition Stage	151
6.3.2	Performance Evaluation of the Second Stage.....	158
6.3.3	Comparison with Other Models	161
6.3.4	Evaluation of the ERLMPSO Model.....	162
6.3.5	Characters Classification	164
6.4	Summary	169

CHAPTER 7 - CONCLUSIONS AND FUTURE WORK

7.1	Summary of the Research	170
7.2	Contributions of the Research.....	172
7.3	Suggestion for Future Work.....	174
	References	176

List of Publications

LIST OF TABLES

		Page
Table 2.1	Summary of the types of PSO-based algorithms	27
Table 2.2	Summary of CI-based plate recognition models	36
Table 2.3	Summary of conventional VLPR models	41
Table 2.4	Summary of vehicle plate characters classification methods	46
Table 3.1	List of parameter settings used in this work	71
Table 3.2	Unimodal and multi-modal benchmarks used in this work	72
Table 3.3	Parameters and levels of the CCD experiment	73
Table 3.4	Effects of delay and cost parameters on proposed RLMP SO	75
Table 3.5	The performance of proposed RLMP SO on different population size	78
Table 3.6	Contribution of each RLMP SO operation	79
Table 3.7	Analysis of the particle execution sequence	82
Table 3.8	Comparison between the RLMP SO results and other reported results in the literature	83
Table 3.9	Results for the composite problems	86

Table 3.10	Average fitness value on composite benchmarks	89
Table 3.11	Results of the gear design problem	91
Table 4.1	The search range for the particle components	105
Table 4.2	Results of model accuracy	112
Table 4.3	Parameters and levels of the CCD experiment	113
Table 4.4	Experimental results of parameter analysis	114
Table 4.5	Comparison with other SVM-based models	118
Table 4.6	The p-values of the performance indicators	119
Table 4.7	Comparison with other computational intelligence models	120
Table 4.8	Reported results in the literature (Agarwalet al., 2004)	122
Table 5.1	Experimental results of the single-stage and two-stage RLMP SO-FSVM models and other methods published in Agarwal et al. (2004)	133
Table 5.2	Comparison with other computational intelligence models	136
Table 5.3	Comparison with other optimizers	137
Table 5.4	The p-values of the performance indicator	138

Table 6.1	Results of system accuracy	152
Table 6.2	Parameters and levels of the CCD experiment	157
Table 6.3	Experimental results of parameter analysis	158
Table 6.4	The effects of the second verification stage on model performance	159
Table 6.5	Performance comparison of different models	162
Table 6.6	Performance comparison in terms of the fitness value with other models	164
Table 6.7	Cases correctly classified	167
Table 6.8	Cases incorrectly classified	167
Table 6.9	Successfully recognized and classified car plates	168

LIST OF FIGURES

		Page
Figure 1.1	The main stages of a pattern recognition model	2
Figure 1.2	(a) Google wearable glasses, and (b) A policeman in Dubai wearing Google glass (Emirates 24 7Channel, 2014)	3
Figure 1.3	Proposed research methodology steps	14
Figure 2.1	A taxonomy of PSO-based algorithms	18
Figure 2.2	VLPR methods	31
Figure 2.3	Illustration of the proposed approach of Yao and Yi (2014)	32
Figure 2.4	Example of connected component parts of a binary image	38
Figure 2.5	Types of vehicle plate character classification methods	42
Figure 2.6	The structure of a character recognition system	43
Figure 3.1	A reinforcement learning model	53
Figure 3.2	The proposed RLMP SO structure	55
Figure 3.3	Five possible states of RLMP SO	58
Figure 3.4	Computation of the initial value of state F at iteration (a) 1 iteration, (b) 100 iterations, and (c)	59

1000 iterations

Figure 3.5	The initial values in the Q-table of particle 1	60
Figure 3.6	The Q-table of Particle 1 after five operations	60
Figure 3.7	The Q-table values of Particle 1 after six operations	61
Figure 3.8	The boundary conditions of PSO (a) reflecting wall, (b) damping wall, (c) invisible wall, and (d) absorbing wall	62
Figure 3.9	Exploration and convergence execution time	63
Figure 3.10	Exploration operation	64
Figure 3.11	Convergence operation	64
Figure 3.12	Jump operation	66
Figure 3.13	F operation	66
Figure 3.14	Delay and cost parameters (a) with low cost, and (b) with high cost value	68
Figure 3.15	A CCD experiment with two parameters and five points (i.e. one center and four corners)	73
Figure 3.16	Average calls of each proposed RLMPSO operation (a) Sphere function, (b) Schwefel function, (c) Ackley function, and (d) Griewank function	76
Figure 3.17	Average percentage of FEs consumed by proposed	77

	RLMPSO operation (a) Sphere function, (b) Schwefel function, (c) Ackley function, and (d) Griewank function	
Figure 3.18	Graphical illustration of proposed RLMPSO particles behaviour on Ackley function (a) particle 1, (b) particle 2, and (c) particle 3	80
Figure 3.19	The mean fitness value reported by RLMPSO as compared with the literature a) Sphere function, (b) Schwefel function, (c) Ackley function, and (d) Griewank function	84
Figure 3.20	Average computational time in seconds on the composite benchmark problems (a) cf1, (b) cf2 ,(c) cf3, (d) cf4, (e) cf5, and (f) cf6	88
Figure 3.21	Gear design problem (Mirjalili et al., 2015)	90
Figure 4.1	The optimal hyperplane where the support vectors are located on the margin	97
Figure 4.2	The effect of parameter r on the location of the decision boundary pertaining to a linear FSVM classifier	100
Figure 4.3	The structure of the proposed RLMPSO-FSVM model	101
Figure 4.4	The RLMPSO operations with the main particle components	102
Figure 4.5	The flowchart of the model construction steps	103

Figure 4.6	Particle components	104
Figure 4.7	Sample images for (a) positive training samples (b) negative training samples (non-car), and (c) test images	107
Figure 4.8	Scanning operation for the target pattern (side view of car)	109
Figure 4.9	Four types of Haar-like wavelet features	110
Figure 4.10	Graphical view illustration (a) model complexity, (b) computational time, and (c) model accuracy	115
Figure 4.11	Samples of successfully detected side-view car images by proposed RLMP SO-FSVM pattern recognition model	116
Figure 5.1	The structure of the proposed two-stage RLMP SO-FSVM model	126
Figure 5.2	Illustration of the proposed model's operation	126
Figure 5.3	ERLMP SO model	127
Figure 5.4	The enhanced F operation	130
Figure 5.5	Component Optimization Operations	131
Figure 5.6	Sample training images for the two-stage model (a) positive training samples for the global recognition stage, (b) positive training samples for the local	132

	recognition stage, and (d) negative training samples for the local recognition stage	
Figure 5.7	Percentage of background rejection by stage I and stage II	134
Figure 5.8	Sample results showing the usefulness of the second verification stage (a) ERLMPSO-FSVM, and (b) two-stage ERLMPSO-FSVM	135
Figure 6.1	Variations in the camera view point	141
Figure 6.2	Variations in types and numbers of characters	141
Figure 6.3	Structure of the VLPR stage	143
Figure 6.4	Illustrative of Gabor filters (a) input image ,and (b) Gabor output image	144
Figure 6.5	Output image thresholding with different values of T (a) T=0.1, (b) T=0.2, (c) T=0.3, (d) T=0.4, and (e) T=0.5	144
Figure 6.6	Image closing operation (a) S=5 pixels, (b) S=10 pixels, and (c) S=15 pixels	145
Figure 6.7	The VLPR stage	146
Figure 6.8	Expanding the two-character window to the right side	147
Figure 6.9	The structure of the character classification stage	148

Figure 6.10	Examples of training images (a) positive training samples, and (b) negative training samples	149
Figure 6.11	Graphical view for evaluation measure	150
Figure 6.12	ROC curve results of ten runs (a) RUN 1, (b) RUN 2, (c) RUN 3, (d) RUN 4, (e) RUN 5, (f) RUN 6, (g) RUN 7, (h) RUN 8, (i) RUN 9, and (j) RUN 10	153
Figure 6.13	Sample results showing the usefulness of the second verification stage (a) ERLMPSO-FSVM, and (b) two-stage ERLMPSO-FSVM	160
Figure 6.14	Positive training samples	165
Figure 6.15	Negative training samples	165

LIST OF ABBREVIATIONS

ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
AIS	Artificial Immune Systems
ANN	Artificial Neural Networks
CI	Computational Intelligence
CNN	Convolution Neural Network
EC	Evolutionary Computation
ERLMPSO	Enhanced Reinforcement Learning-based Memetic Particle Swarm Optimization
FPGA	Field Programmable Gate Array
FS	Fuzzy Systems
FSVM	Fuzzy Support Vector Machine
GA	Genetic Algorithm
GWO	Grey Wolf Optimizer
HOG	Histogram of Oriented Gradients
HS	Harmony Search

KNN	K-Nearest Neighbor
LBP	Local Binary Pattern
MLP	Multi-Layer Perceptron
MVO	Multi-Verse Optimizer
NBC	Naive Bayes Classifier
PCNN	Pulse-Coupled Neural Network
LPR	License Plate Recognition
PSO	Particle Swarm Optimization
RBF	Radial Basis Function
RL	Reinforcement Learning
RLMPSO	Reinforcement Learning-based Memetic Particle Swarm Optimization
SI	Swarm Intelligence
SIFT	Scale-Invariant Feature Transform
SOM	Self-Organization Map
SVM	Support Vector Machine
TDNN	Time-Delay Neural Network

MODEL BERASASKAN PENGOPTIMUMAN KAWANAN ZARAH YANG DITINGKATKAN DAN APLIKASI MEREKA UNTUK PENGECEMAN PLAT LESEN

ABSTRAK

Model pengecaman corak memainkan peranan yang penting dalam banyak aplikasi dunia sebenar seperti pengesanan teks dan pengecaman objek. Pelbagai kaedah termasuk model Kecerdikan Berkomputer (CI) telah dibangunkan untuk menangani masalah pengecaman corak berasaskan imej. Tertumpu kepada model CI, penyelidikan ini mempersembah model berasaskan pengoptimuman kawanan zarah (PSO) yang cekap serta aplikasinya untuk pengecaman lesen plat. Pertama, model Pengoptimuman Kawanan Zarah Memetik berasaskan pengukuhan pembelajaran yang baharu (RLMPSO) diperkenalkan. Masalah pengoptimuman penanda aras digunakan untuk menilai prestasi RLMPSO, dan kaedah *bootstarp* digunakan untuk menilai keputusan secara statistik. Kedua, RLMPSO disepadukan dengan mesin Penyokong Vektor Kabur (FSVM) untuk merumuskan model RLMPSO-FSVM yang cekap. Secara khusus, RLMPSO-FSVM terdiri daripada gabungan pengelas linear FSVM yang dibina menggunakan RLMPSO untuk melaksanakan penalaan parameter, pemilihan ciri, serta pemilihan contoh latihan. Untuk menilai prestasi model RLMPSO-FSVM yang dicadangkan, pangkalan data imej penanda aras digunakan. Ketiga, model dua-peringkat RLMPSO-FSVM dicipta untuk mempertingkatkan lagi kecekapan. Ia mengandungi peringkat pengecaman global dan peringkat pengesanan tempatan. Peningkatan model RLMPSO turut diperkenalkan dengan memasukkan operasi carian tambahan. Model RLMPSO yang (ERLMPSO) dipertingkatkan terdiri daripada tiga lapisan, iaitu lapisan global

dengan empat operasi carian, lapisan tempatan dengan satu operasi carian, dan lapisan berasaskan komponen dengan dua belas operasi carian. Akhir sekali, model dua-peringkat ERLMPSO-FSVM yang dicadangkan telah digunakan dalam masalah Pengecaman Plat Lesen Kereta Malaysia (VLPR) yang sebenar. Kadar pengecaman setinggi 98.1% telah diperolehi. Keputusan ini mengesahkan keberkesanan model dua-peringkat ERLMPSO-FSVM yang dicadangkan dalam menangani masalah pengecaman plat lesen.

ENHANCED PARTICLE SWARM OPTIMIZATION-BASED MODELS AND THEIR APPLICATION TO LICENSE PLATE RECOGNITION

ABSTRACT

Pattern recognition models play an important role in many real-world applications such as text detection and object recognition. Numerous methodologies including Computational Intelligence (CI) models have been developed in the literature to tackle image-based pattern recognition problems. Focused on CI models, this research presents efficient Particle Swarm Optimization (PSO)-based models and their application to license plate recognition. Firstly, a new Reinforcement Learning-based Memetic Particle Swarm Optimization (RLMPSO) model is introduced. To assess the performance of RLMPSO, benchmark optimization problems are employed, and the bootstrap method is used to quantify the results statistically. Secondly, RLMPSO is integrated with the Fuzzy Support Vector Machine (FSVM) to formulate an efficient RLMPSO-FSVM model. Specifically, RLMPSO-FSVM comprises an ensemble of linear FSVM classifiers that are constructed using RLMPSO to perform parameter tuning, feature selection, as well as training sample selection. To evaluate the performance of the proposed RLMPSO-FSVM model, a benchmark image database is employed. Thirdly, to further improve efficiency, a two-stage RLMPSO-FSVM model is devised. It consists of a global recognition stage and a local verification stage. In addition, enhancement of the RLMPSO model is introduced by incorporating additional search operations. The enhanced RLMPSO model (i.e. ERLMPSO) comprises three layers, namely, a global layer with four

search operations, a local layer with one search operation, and a component-based layer with twelve search operations. Finally, the proposed two-stage ERLMPSO-FSVM model is applied to a real-world Malaysian vehicle license plate recognition (VLPR) task. A high recognition rate of 98.1% has been achieved, confirming the effectiveness of the proposed two-stage ERLMPSO-FSVM model in tackling the license plate recognition problem.