The series “Studies in Computational Intelligence” (SCI) publishes new developments and advances in the various areas of computational intelligence—quickly and with a high quality. The intent is to cover the theory, applications, and design methods of computational intelligence, as embedded in the fields of engineering, computer science, physics and life sciences, as well as the methodologies behind them. The series contains monographs, lecture notes and edited volumes in computational intelligence spanning the areas of neural networks, connectionist systems, genetic algorithms, evolutionary computation, artificial intelligence, cellular automata, self-organizing systems, soft computing, fuzzy systems, and hybrid intelligent systems. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution, which enable both wide and rapid dissemination of research output.

The books of this series are submitted to indexing to Web of Science, EI-Compendex, DBLP, SCOPUS, Google Scholar and Springerlink.

More information about this series at http://www.springer.com/series/7092
Nature-Inspired Optimizers
Theories, Literature Reviews and Applications
To our parents
Preface

One of the fastest growing sub-fields of Computational Intelligence and Soft Computing is Evolutionary Computation. This field includes different optimization algorithms that are suitable for solving NP-hard problems for which exact methods are not efficient. Such algorithms mostly use stochastic operators and are gradient-free, which makes them suitable for solving nonlinear problems, particularly those for which objectives are noisy, multi-modal, or expensive to evaluate.

The main purpose of this book is to cover the conventional and most recent theories and applications in the area of Evolutionary Algorithms, Swarm Intelligence, and Meta-heuristics. The chapters of this book are organized based on different algorithms in these three classes as follows:

- Ant Colony Optimizer
- Ant Lion Optimizer
- Dragonfly Algorithm
- Genetic Algorithm
- Grey Wolf Optimizer
- Grasshopper Optimization Algorithm
- Multi-Verse Optimizer
- Moth-Flame Optimization Algorithm
- Salp Swarm Algorithm
- Sine Cosine Algorithm
- Whale Optimization Algorithm

Each chapter starts by presenting the inspiration(s) and mathematical model(s) of the algorithm investigated. The performance of each algorithm is then analyzed on several benchmark case studies. The chapters also solve different challenging problems to showcase the application of such techniques in a wide range of fields. The problems solved are in the following areas:

- Path planning
- Training neural networks
- Feature selection
• Image processing
• Computational fluid dynamics
• Hand gesture detection
• Data clustering
• Optimal nonlinear feedback control design
• Machine learning
• Photonics

Brisbane, Australia
August 2018

Dr. Seyedali Mirjalili
Prof. Jin Song Dong
Dr. Andrew Lewis
Contents

Introduction to Nature-Inspired Algorithms .................................................. 1
Seyedali Mirjalili and Jin Song Dong
Reference ................................................................. 5

Ant Colony Optimizer: Theory, Literature Review, and Application
in AUV Path Planning .................................................. 7
Seyedali Mirjalili, Jin Song Dong and Andrew Lewis
1 Introduction ............................................................ 7
2 Inspiration ............................................................. 8
3 Mathematical Model ..................................................... 9
   3.1 Construction Phase ............................................... 10
   3.2 Pheromone Phase ............................................... 11
   3.3 Daemon Phase .................................................. 12
   3.4 Max-Min Ant System ............................................ 12
   3.5 Ant Colony System ............................................. 13
   3.6 Continuous Ant Colony ....................................... 13
4 Application of ACO in AUV Path Planning ................................. 14
5 Conclusion ............................................................ 20
References ................................................................. 20

Ant Lion Optimizer: Theory, Literature Review, and Application
in Multi-layer Perceptron Neural Networks ........................................... 23
Ali Asghar Heidari, Hossam Faris, Seyedali Mirjalili, Ibrahim Aljarah
and Majdi Mafarja
1 Introduction ............................................................ 24
2 Ant Lion Optimizer ..................................................... 25
3 Literature Review ...................................................... 28
4 Perceptron Neural Networks .......................................... 30
5 ALO for Training MLPs ............................................. 31
6 Results and Discussions ............................................. 33
Moth-Flame Optimization Algorithm: Theory, Literature Review, and Application in Optimal Nonlinear Feedback Control Design ........................................ 143
Seyed Hamed Hashemi Mehne and Seyedali Mirjalili
1 Introduction ........................................................................... 143
2 Moth Flame Optimization Method ....................................... 145
   2.1 Background and Motivation ........................................... 145
   2.2 Explanation of MFO .................................................... 146
   2.3 Inspiration from Moths ................................................ 146
   2.4 The MFO Algorithm .................................................... 146
3 Literature Review of MFO .................................................. 151
   3.1 Variants .................................................................... 152
   3.2 Applications ............................................................. 152
4 MFO for Optimal Control Problems .................................... 153
   4.1 Problem Definition ...................................................... 154
   4.2 Collocation ............................................................... 155
5 Numerical Examples ......................................................... 156
   5.1 Example 1. Rotational/Translational Actuator ................. 156
   5.2 Example 2. F-8 Aircraft ................................................. 159
6 Conclusion ............................................................................ 160
References ............................................................................. 161

Particle Swarm Optimization: Theory, Literature Review, and Application in Airfoil Design .................................................. 167
Seyedali Mirjalili, Jin Song Dong, Andrew Lewis and Ali Safa Sadiq
1 Introduction ........................................................................... 167
2 Particle Swarm Optimization ................................................. 168
3 Results .................................................................................. 172
   3.1 Exploration and Exploitation in PSO .............................. 172
   3.2 2D Airfoil Design Using PSO ......................................... 177
4 Conclusion ............................................................................ 183
References ............................................................................. 183

Salp Swarm Algorithm: Theory, Literature Review, and Application in Extreme Learning Machines ........................................... 185
Hossam Faris, Seyedali Mirjalili, Ibrahim Aljarah, Majdi Mafarja and Ali Asghar Heidari
1 Introduction ........................................................................... 185
2 Extreme Learning Machines ............................................... 187
3 Salp Swarm Algorithm ......................................................... 188
4 Literature Review ............................................................... 190
5 Proposed SSA-ELM Approach ............................................ 191
6 Experiments and Results ..................................................... 192
7 Conclusion and Future Directions ........................................ 196
References ............................................................................. 196
# Sine Cosine Algorithm: Theory, Literature Review, and Application in Designing Bend Photonic Crystal Waveguides

Seyed Mohammad Mirjalili, Seyedeh Zahra Mirjalili, Shahrzad Saremi and Seyedali Mirjalili

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction</td>
<td>201</td>
</tr>
<tr>
<td>2 Sine Cosine Algorithm</td>
<td>203</td>
</tr>
<tr>
<td>3 Literature Review of SCA</td>
<td>206</td>
</tr>
<tr>
<td>3.1 Variants</td>
<td>206</td>
</tr>
<tr>
<td>3.2 Application</td>
<td>207</td>
</tr>
<tr>
<td>4 Results</td>
<td>208</td>
</tr>
<tr>
<td>4.1 Solving Benchmark Functions Using SCA</td>
<td>208</td>
</tr>
<tr>
<td>4.2 Designing Bend Photonic Crystal Waveguides Using SCA</td>
<td>211</td>
</tr>
<tr>
<td>5 Conclusion</td>
<td>213</td>
</tr>
<tr>
<td>References</td>
<td>214</td>
</tr>
</tbody>
</table>

# Whale Optimization Algorithm: Theory, Literature Review, and Application in Designing Photonic Crystal Filters

Seyedehzahra Mirjalili, Seyed Mohammad Mirjalili, Shahrzad Saremi and Seyedali Mirjalili

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Introduction</td>
<td>219</td>
</tr>
<tr>
<td>2 Whale Optimization Algorithm</td>
<td>221</td>
</tr>
<tr>
<td>3 Literature Review of WOA</td>
<td>224</td>
</tr>
<tr>
<td>3.1 Variants</td>
<td>224</td>
</tr>
<tr>
<td>3.2 Applications</td>
<td>225</td>
</tr>
<tr>
<td>4 Results</td>
<td>226</td>
</tr>
<tr>
<td>4.1 Results of WOA on Benchmark Functions</td>
<td>226</td>
</tr>
<tr>
<td>4.2 Results of WOA When Designing Photonic Crystal Filters</td>
<td>229</td>
</tr>
<tr>
<td>5 Conclusion</td>
<td>233</td>
</tr>
<tr>
<td>References</td>
<td>233</td>
</tr>
</tbody>
</table>
Contributors

Ibrahim Aljarah King Abdullah II School for Information Technology, The University of Jordan, Amman, Jordan

Jin Song Dong Institute for Integrated and Intelligent Systems, Griffith University, Nathan, Brisbane, QLD, Australia; Department of Computer Science, School of Computing, National University of Singapore, Singapore, Singapore

Hossam Faris King Abdullah II School for Information Technology, The University of Jordan, Amman, Jordan

Ali Asghar Heidari School of Surveying and Geospatial Engineering, University of Tehran, Tehran, Iran

Andrew Lewis Institute for Integrated and Intelligent Systems, Griffith University, Nathan, Brisbane, QLD, Australia

Majdi Mafarja Department of Computer Science, Faculty of Engineering and Technology, Birzeit University, Birzeit, Palestine

Seyed Hamed Hashemi Mehne Aerospace Research Institute, Tehran, Iran

Seyedali Mirjalili Institute for Integrated and Intelligent Systems, Griffith University, Nathan, Brisbane, QLD, Australia

Seyed Mohammad Mirjalili Department of Electrical and Computer Engineering, Concordia University, Montreal, QC, Canada

Seyedali Mirjalili Institute of Integrated and Intelligent Systems, Griffith University, Nathan, Brisbane, QLD, Australia; School of Information and Communication Technology, Griffith University, Brisbane, QLD, Australia

Seyedeh Zahra Mirjalili School of Electrical Engineering and Computing, University of Newcastle, Callaghan, NSW, Australia
Ali Safa Sadiq  School of Information Technology, Monash University, Bandar Sunway, Malaysia

Shahrzad Saremi  Institute for Integrated and Intelligent Systems, Griffith University, Brisbane, QLD, Australia