Review of the Ph.D. Thesis

Development and Modification of Modern Bio-Inspired Swarm Algorithms

By: Anežka Kazikova

Overview

The Candidate deals with a very important topic of quality of development of new metaheuristics in the field of optimization algorithms (the topic is similarly relevant for other fields within artificial intelligence as well). The dissertation topic as such is very timely and valuable. The Candidate presents and discusses the issues encountered in the development of new metaheuristics (questionable novelty, poor experimentation, inappropriate presentation, implications that come with these issues) and proposes guidelines on how a researcher should approach the development of new metaheuristics from algorithm design to analysis of the results. The Candidate also applied the guidelines to a selected use case.

The dissertation has set the following goals:

- Present an overview of modern swarm-based algorithms.
- Investigate common approaches to weaknesses observed with swarm-based algorithms.
- Propose a set of guidelines for the appropriate development of new metaheuristics.
- Provide an example of following guidelines on the selected Bison Algorithm use case.
- Evaluate the benefits of the proposed Bison Algorithm (and its modifications) on various applications.

I believe that all the goals were met within the dissertation.

The Candidate has thoroughly investigated metaheuristics, particularly swarm-based algorithms. From the large amounts of metaheuristics (probably over a hundred), relatively small (unresearched) differences, and various articles that pinpoint many issues that have arisen in recent years with the explosion of new nature-inspired swarm-based algorithms, the Candidate has concluded that there are big issues that need to be tackled/resolved in how researchers approach the development of new metaheuristics. As established by the author, many papers are identifying the issues but too little is done on the promotion of better / appropriate development of new metaheuristics. To this end, the Candidate devised the process of developing new metaheuristics into basic steps and for each of them provided guidelines on how they should be addressed to minimize the risk of performing inadequate optimization algorithm development that led to the current state in the optimization community. Furthermore, the Candidate provides an example of following the guidelines on the development of the Bison Algorithm with of goal of improving the algorithm's capabilities for escaping local optima.

The dissertation is nicely prepared and well structured. The thesis contains an abstract, table of contents, list of figures, list of tables, and list of abbreviations, followed by nine main chapters. The thesis concludes with references, publications of the author, curriculum vitae, and five appendices.
In the first two chapters, the Candidate introduces the topic by describing metaheuristic optimization. The Candidate primarily focuses on popular metaheuristic algorithms, their classifications, and issues that are being encountered by metaheuristics. The third chapter focuses on popular swarm-based algorithms, general criticism that is often met with the introduction of "new" optimization algorithms, and recommendations on how the development of new metaheuristic algorithms should be approached to minimize the previously mentioned criticisms. Chapter four describes the goals and methods used in the dissertation. Chapter five introduces the standard Bison Algorithm, while further modifications, to improve capabilities of escaping out of local optima, are presented in chapter six. Here a special focus was given to the comparison of algorithms performances concerning the

efficiency of escaping local optima. The performance of the Bison Algorithm in comparison to selected popular swarm algorithms on a well-known benchmark set is performed in chapter seven. In addition, a comparison with the two state-of-the-art algorithms is performed to observe not only capabilities of escaping local optima, but also performance against currently best-performing algorithms. The thesis concludes with a chapter where meanings for the applied sciences are presented and a final chapter where concluding thoughts are given.
The dissertation is written in an acceptable level of English and the text is easy to read.
The Candidate published four journal articles (three as a first author). One of the journals has an impact factor greater than three. The Candidate also published ten articles in conference proceedings (seven as a first author) with the majority of them published in various Lecture Notes.
With this, the Candidate shows expected publication activity.

In conclusion, the thesis can be considered complete, and all goals have been fulfilled.

The research contribution of the work (Candidate's contribution)

The main contribution of this dissertation and the Candidate's research contribution to the field of optimization can be summarized as:

- An in-depth overview of modern metaheuristics with a special focus on swarm-based algorithms.
- Investigated typical algorithms' weaknesses and common approaches to resolving them.
- Proposed guidelines for appropriate development of new metaheuristics.
- Proposed a new swarm-based metaheuristic: Bison Algorithm.
- Developed new variants of the Bison Algorithm using proposed guidelines.
- Evaluated modifications of the Bison Algorithm on various applications.

I would like to especially emphasize the importance of guidelines for the appropriate optimization algorithm development and acceptance of newly developed metaheuristics. They should be followed by every researcher since this would be an important step in the reduction of various issues that plague the modern optimization community.

Formal remarks

- I wish that the Candidate would go further with using standard vocabulary. Any "terms" related to the motivation/inspiration should not be present in the algorithm presentation (pseudocodes, description, etc.). E.g., usage of terms like swarmer, runner, running group, running solutions, etc.
- In pseudocodes and figures, some details are missing or are not explained. E.g., running group (RG) size is not defined.
- Some interpretations of statistical results are not appropriate. E.g., stating the following: "despite the success of the Wilcoxon Rank-Sum test". The test does not measure success. Also, when using multiple independent pairwise tests for one vs. all comparisons one must always use an appropriate post-hoc procedure to identify if one algorithm is statistically significantly different (better) than all the others.

Conclusion

In my opinion, the Ph.D. Candidate Anežka Kazikova has presented the knowledge and capabilities of understanding important issues in the research field of computational intelligence and has provided guidelines for their improvement. The Candidate has performed recognized research work under the guidance of the supervisor Assoc. prof. Ing. Roman Senkerik and advisor Ing. Michal Pluhacek. The dissertation represents a solid basis, from both practical and experimental points of view, for further follow-up research and can have a positive influence on the optimization community in the future. The research is relevant, supported by the strong experimental design, and shows how the development of new algorithms should be approached. Publications of the Candidate are good, as proved by the number of papers in journals (IEEE Access with IF 3.367) and the respected conferences in the field.

Despite the minor remarks,

I recommend,

Anežka Kazikova's Ph.D. thesis is to be accepted and defended for the award of the Ph.D. degree.

In Ljubljana: 21. 9. 2022

Prof. dr. Peter Korošec
Jožef Stefan Institute
Department of Computer Systems
1000 Ljubljana, Slovenia

PETER KOROŠEC

Digitally signed by PETER KOROŠEC
DN: c=SI, st=Slovenija, 2.5.4.97=VATSI-55560822, o=IJS V ANGLJEZIKU: JSI, givenName=PETER, sn=KOROŠEC, serialNumber=2465353616038, cn=PETER KOROŠEC
Date: 2022.09.26 09:01:09 +01'00'

VSB TECHNICAL UNIVERSITY OF OSTRAVA | FACULTY OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE | DEPARTMENT OF COMPUTER SCIENCE

Dissertation thesis review

The dissertation thesis entitled „**Development and Modification of Modern Bio-inspired Swarm Algorithms**", submitted by **Ing. Anežka Kazíková** summarizes the author's research and results in the field of swarm intelligence. In particular, it provides a comprehensive mapping of the state-of-the-art in swarm intelligence and the description of the development of an own bio-inspired optimization algorithm titled the Bison Algorithm. The thesis has two major goals: the documentation and critical assessment of the current state-of-the-art in the field of swarm intelligence (in the broadest sense) and the design of an own algorithm drawing inspiration from unique optimization strategies observed in nature.

Both objectives correspond to up-to-date research problems and are successfully addressed by the presented research. The author dedicates the first half of the thesis (secs. 1 – 3.) to the introduction to the matter, a description of seminal bio-inspired algorithms (starting with genetic algorithms and finishing with evolutionary strategies) and their classification, a gentle introduction to swarm intelligence a specific field within bio-inspired optimization, and summary of guidelines for the development of new metaheuristic algorithms. Particular usefulness can be attributed to subsections describing typical challenges of bio-inspired methods (sec. 2.3), usual modifications that are often applied to bio-inspired methods (sec. 2.4), and the general guidelines that were proposed for the serious and sound development of novel bio-inspired methods (sec. 3.3). Sections 5 to 8 are dedicated to the description and analysis of author's own contribution to the field of swarm algorithms, the Bison Algorithm (BA). Finally, section 9 concludes the work.

The structure of the manuscript is generally alright. The only problem I see is the somewhat unusual placement of the Goals and Methods section in the middle of the book while one would expect this to be presented to the reader at the beginning of the text. Apart from that, the thesis is well-written and reads smoothly. All important decisions (e.g., the selection of influential algorithms to be described in sec. 2.1, the classification system of sec. 2.2., etc.) are explained in a sound and reasonable manner. The design of a new bio-inspired method is well-motivated, too. The description of the BA and its modifications is clear and the computational experiments outlined on several batteries of benchmarking functions suggest its validity.

From the technical point of view, several comments can be made. First of all, the technical description of the algorithms is not perfect. The manuscript suffers from inconsistency which is apparently the result of taking the description of the algorithms from different original sources. This is of course not a problem, *per se*, but it is an important part of the job of the author to unify the notation and use a systematic and clear way of describing the working of the algorithms throughout the manuscript. What we see here is a different notation for vectors/elements in (2.2) – (2.3), different in (2.6) – (2.10), different in (3.1) – (3.2), different in (3.6), etc. Some equations contain symbols that are not properly explained (e.g., λ in eq. (3.9), (3.10)), and some formulations are slightly confusing (e.g., "premature stagnation" on p. 42 - should likely be either premature convergence or [early] stagnation, etc.). Some methodological choices can be questioned, as well. It is, for example, not really clear whether the queries used to generate the plots in fig. 2.10 really grasp the entirety of development on the field. However, the outcome of the literature survey is not put at risk by this.

17. listopadu 2172/15
708 00 Ostrava-Poruba
Czech Republic

phone: +420 597 325 898
attendant: +420 597 321 111
ID data mailbox: d3kj88v

IČO: 61989100
VATIN: CZ61989100

email: pavel.kromer@vsb.cz
www.vsb.cz

The main problem of the thesis is the internal conflict inflicted by putting its two parts side by side. The first one provides a much-needed critical review and summary of guidelines for the development of metaheuristics. The second one, on the other hand, describes the development and pedigree of exactly one of them. In sec. 8.2, the author claims that the guidelines for algorithm design and evaluation are followed. However, they are not followed perfectly according to this reviewer. The name of the method (Bison Algorithm) appears to be metaphor-based, the vocab is a mixture of standard and algorithm specific (running/swarming group vs. sub-populations), and the comparison with algorithms operating on similar principles (e.g., with structured populations with a different focus on exploitation/exploration, multiple sub-populations, etc.) is not provided at all and the test benchmarks are selected arbitrarily (why CEC 15/CEC 17 and not BBOB, COCO, large-scale problems? why not simulation or real-world-based benchmarks?).

Finally, the evaluation of algorithm complexity (albeit based on CEC competition standards), is of only little use. Instead, a statistical/visual analysis and comparison of the algorithms' behaviour (e.g., of the dependence of solution accuracy on the number of fitness function evaluations) and the time and space complexity of the overhead of each algorithm would be generally more helpful. The plots in fig. 7.8, for example, are almost misleading: the dimension on the y-axis of the last 5 plots is not unified, average fitness at each evaluation is not shown, confidence intervals are missing, etc. Fig. 7.9 does a better job in providing a comparison between the algorithms, but only for a different set of benchmarking functions ...

Nevertheless, and despite the critical remarks, it can be clearly concluded that the thesis is of high quality and fully meets the requirements on a dissertation thesis. The research of the candidate has been published in 4 journal publications and proceedings of 10 conferences, including GECCO, CEC, and SSCI, which is a clear sign of acceptance of the proposed ideas by the relevant scientific community. Therefore, it is my pleasure to, **recommend the thesis for defense** and Ing. Anežka Kazíková for the academic degree of ***doctor Philosophiae*** **(Ph.D.)**.

Pavel Krömer, Ph.D.
In Ostrava, 03. 10. 2022

17. listopadu 2172/15
708 00 Ostrava-Poruba
Czech Republic

phone: +420 597 325 898
attendant: +420 597 321 111
ID data mailbox: d3kj88v

IČO: 61989100
VATIN: CZ61989100

email: pavel.kromer@vsb.cz
www.vsb.cz

Review of the Ph.D. Thesis

Title: Development and Modification of Modern Bio-Inspired Swarm Algorithms
Author: Anežka Kazíková

Overview

The thesis is structured into nine main sections and five appendices. The first three sections introduce the current trends and challenges in the field of metaheuristic optimization, with a specific focus on so-called swarm algorithms. The level of English is excellent, and the thesis reads easily. The fourth section introduces the goals of the thesis, which are:

1. Map the current scene of modern swarm algorithms, its trends, and challenges.
2. Investigate the methods addressing the weaknesses of swarm algorithms.
3. Propose a set of recommendations for new metaheuristics creation.
4. Proof of concept testing: Implement the proposed recommendations and methods in a new swarm algorithm.
5. Evaluate the benefits of the proposed algorithm for applied sciences

The following sections five, six, and seven describe the development, modifications, and performance testing of the original metaheuristic algorithm called the "Bison Algorithm" that the Author of the thesis proposed. While the Author introduced a set of guidelines for designing a new metaheuristic algorithm, it seems that not all (e.g., the terminology) were strictly followed during the development of the Bison algorithm. According to the Author, the Bison algorithm is designed in such a way that it should avoid local optima entrapment. To this end, the Author proposes several subsequent modifications to the original algorithm. The performance of the Bison algorithm is tested and compared with several selected representatives of swarm algorithms.
Section eight, titled "Meaning For Applied Science," presents a much-needed deep discussion of the presented work in a broader context. Among others, the Author presents a real-world application of the Bison algorithm - a PID controller design, showing the viability of the proposed method. The thesis concludes in section nine.

The topic of the thesis is actual and important. The state-of-the-art introduction and problem statement are clear and persuasive. The Author shows a high level of knowledge and overview of the research field (Appendix A serves as a good example). The identified challenges and proposed recommendations to tackle them are sound and beneficial. The proposed Bison algorithm shows some promising performance, however, more thorough performance testing and comparison with state-of-the-art methods would be beneficial. The Author should put such a study on her future work list.
Nevertheless, the Bison algorithm exhibits the desired behavior in experiments with artificial benchmark functions and superior performance in a real-world application. The discussion and evaluation of the work are, again, thorough and sound. Therefore, all goals of the work have been fulfilled.

Research contribution of the work (Author's own contribution)

The main contribution of this thesis and the Author's research contribution can be summarized as follows:

- Thorough literature overview and state-of-the-art analysis.
- Identification of main challenges for metaheuristic design and detailed recommendations to tackle them.
- Proposal of original metaheuristic Algorithm with a focus on local entrapment avoidance.
- Real-world application of the proposed algorithm in an international research effort.

Formal remarks

- The structure of the thesis could be improved. Notably, some goals presented in section 4 seem to be already addressed in section 3.3.
- There is an inconsistency in the symbol and parameter notation throughout the work.

Final conclusion

The Author has shown the ability to conduct systematic research on an important and actual topic. The conclusions and results of the work are persuasive, supported by data, and beneficial to the research field. The presented work is a valuable addition to the research efforts of metaheuristic optimization and artificial intelligence in general.

The Author's list of publications shows a healthy quality/quantity ratio with four journal papers and ten conference papers, including a first-author publication with an international author team. The quality of publications (namely IEEE Access journal and several IEEE conferences) proves the acceptance of the Author's research work by experts in the field.

As a result, despite the minor remarks,

I recommend,

Anezka Kazikova's Ph.D. thesis to be accepted and defended for the award of the Ph.D. degree.

In Brno: 10.10.2022

prof. ing. Petr Dostál, CSc.

Brno University of Technology
Faculty of Business and Management
Department of Informatics
Brno, Czech Republic