FINITE IMPULSE RESPONSE OPTIMIZERS FOR SOLVING OPTIMIZATION PROBLEMS

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DOCTOR OF PHILOSOPHY

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Engineering • Technology • Creativity

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Mechanical & Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

AUGUST 2019

ACKNOWLEDGEMENTS

In the name of Allah, the Most Beneficent, the Most Merciful. Praise is to Allah who gave me the strength and the guidance to accomplish this work.

Firstly, I would like to express my sincere gratitude to my supervisor, Assoc. Professor Dr. Zuwairie bin Ibrahim and to my field supervisor, Dr. Nor Azlina Binti Ab. Aziz for their guidance throughout my research. Many thanks to Assoc. Professor Shunyi Zhao from Jiangnan University who helped me to understand the concept of the UFIR filter.

Secondly, I would also like to thank all members of staffs in the Faculty of Mechanical & Manufacturing Engineering, Institute of Postgraduate Studies, and Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang (UMP), as well as Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), and Multimedia University Malaysia (MMU).

To my panels, Dr. Muhammad Sharfi bin Najib, Dr. Ahmad Afif bin Mohd Faudzi, Dr. Dwi Pebriati, Dr. Mohd Shakirin bin Ramli, Dr. Nor Maniha Binti Abd Ghani, Ts. Dr. Nafrizuan bin Mat Yahaya, Dr. Muhammaad Aizat bin Zakaria, Assoc. Professor Dr. Mohd Nizam bin Mohmad Kahar, Assoc. Professor Dr. Rohani Binti Abu Bakar, Prof. Ts. Dr. Kamal Zuhairi bin Zamli, Prof. Dr. Salwani Binti Abdullah, Assoc. Professor Dr. Siti Zaiton Binti Mohd Hashim, Prof. Abdullah bin Ibrahim, Dr. Ahmad Shahir bin Jamaludin, and Dr. Ahmad Fahkri bin Ab. Nasir, thank you for fruitful discussion during either progress presentations, proposal defense, pre-viva, and viva session.

I would like to thank my employer, UTHM and to the Ministry of Higher Education Malaysia for supporting me financially through Skim Latihan Akademik Bumiputera (SLAB), and not forgotten to my guarantors.

Thank you to members of *Legion of SKF and FIROs* for providing interesting comments and support in our series of supervisory meetings.
Last but not least, I would like to thank my parents, Ab Rahman bin Yatim and Che Hasnah Binti Mahmud, my sons, Ahmad Naimdanish bin Muhamad Naim and Ahmad NaimHadeef bin Muhamad Naim, my brother, Tasirihafizan bin Ab Rahman, my sister in law, Aziah Binti Abdollah, my niece, Annur Azimah Binti Tasirihafizan, and to all my relatives and friends for your support and prayers.

ABSTRAK

Masalah pengoptimuman sering ditemui dalam pelbagai bidang. Pengelasan algoritma metaheuristik berasaskan anggaran telah diperkenalkan bagi menyelesaikan masalah pengoptimuman. Algoritma Kalman Penapis Simulasi (SKF) adalah salah satu algoritma di bawah klasifikasi ini. SKF diilhami oleh rangka kerja penapis Kalman (KF) iaitu penganggar yang popular bagi menyelesaikan masalah anggaran. SKF memerlukan parameter keadaan awalan, ralat kovarian awalan, hingar pengukuran, dan hingar proses untuk beroperasi. Namun, tiada kajian penalaan parameter dijalankan bagi kesemua parameter SKF. Memilih nilai parameter optimal dapat meningkatkan prestasi algoritma. Ini boleh dilakukan melalui eksperimen penalaan parameter. Namun, penalaan beberapa parameter adalah tugas yang mencabar dan memakan masa. Oleh itu, kajian ini cuba mengguna pakai strategi pencarian baru dari penganggar popular yang lain, dinamakan Penapis sambutan dedenyut terhingga saksama lelaran muktamad (UFIR) yang bekerja dengan hanya satu parameter. Penapis UFIR adalah salah satu daripada variasi penapis sambutan dedenyut terhingga (FIR). Penapis FIR diperkenalkan untuk mengatasi had dalam penapis KF yang mempunyai beberapa parameter yang sukar ditentukan dalam aplikasi-nyata. Dalam kerja ini, tiga algoritma baru metaheuristik berasaskan anggaran diperkenalkan. Algoritma pertama adalah algoritma berasaskan ejen-tunggal, dinamakan pengoptimum FIR ejen-tunggal (SAFIRO). Algoritma kedua adalah algoritma berasaskan ejen-berbilang dengan mekanisme kemas kini segerak, dinamakan pengoptimum FIR ejen-berbilang (MAFIRO). Algoritma ketiga adalah algoritma berasaskan agen-berbilang dengan mekanisme kemas kini tak segerak, dinamakan pengoptimum FIR tak segerak (AFIRO). SAFIRO berbeza daripada MAFIRO dari segi bilangan ejen. Manakala, MAFIRO berbeza daripada AFIRO dari segi strategi pencarian lelaran. Ketiga-tiga algoritma ini dipanggil secara pendek sebagai pengoptimum-pengoptimum FIR (FIROs). Setiap ejen FIROs bertanggungjawab mencari penyelesaian dengan melakukan pengukuran dan anggaran. Semasa pengukuran, FIROs menggunakan mutasi rawak bagi penyelesaian terbaik setakat ini beserta kaedah kejiranan tempatan untuk mengimbangi antara proses penjelajahan dan eksploitasi. Nilai pengukuran ini kemudiannya digunakan dalam anggaran bagi menambah baik penyelesaian secara lelaran. Prestasi FIROs diuji dengan menyelesaikan suit tanda aras CEC 2014. Kompetensi FIROs dibandingkan secara statistik dengan empat algoritma metaheuristik sedia ada: SKF, penyelesaian-tunggal SKF (ssSKF), Pengoptimuman kerumunan zarah (PSO), dan algoritma Genetik (GA). Analisis statistik menggunakan ujian Friedman dan ujian Holm post hoc dilaksanakan untuk membariskan prestasi FIROs. Ujian Friedman menunjukkan SAFIRO mempunyai baris tertinggi, diikuti oleh MAFIRO, AFIRO, ssSKF, SKF, PSO, dan GA. Ujian Holm post hoc mendedahkan prestasi SAFIRO nyata lebih baik daripada SKF, ssSKF, PSO, dan GA. Manakala, prestasi kedua-dua MAFIRO dan AFIRO nyata lebih baik daripada PSO dan GA, tetapi setara dengan SKF dan ssSKF. SAFIRO, MAFIRO, dan AFIRO memberikan prestasi yang setara. Walau bagaimanapun, SAFIRO boleh dianggap sebagai algoritma terbaik dengan baris tertinggi Friedman dan jumlah tertinggi prestasi terbaik dalam menyelesaikan suit tanda aras CEC 2014. Penemuan menunjukkan konsep penapis UFIR adalah inspirasi yang baik bagi algoritma metaheuristik. Algoritma-algoritma metaheuristik baru berasaskan penganggaran ini boleh menawarkan hasil yang diharapkan bagi menyelesaikan masalah pengoptimuman.

ABSTRACT

Optimization problems are frequently found in various fields. The classification of estimation-based metaheuristic algorithms has been introduced for solving optimization problems. Simulated Kalman filter (SKF) algorithm is one of the algorithms under this classification. SKF is inspired by the framework of Kalman filter (KF) which is a popular estimator for solving estimation problems. SKF needs parameters of the initial error covariant, measurement noise, and process noise to operate. Nonetheless, no study on parameter tuning being carried out for all SKF's parameters. Selecting optimal parameters' values may improve an algorithm's performance. This can be done through parameter tuning experiment. However, tuning several parameters is a challenging task and time-consuming. Thus, this study attempts to adopt a new search strategy from another popular estimator, named the Ultimate iterative unbiased finite impulse response (UFIR) filter which works with only one parameter. UFIR filter is one of the variants of the finite impulse response (FIR) filter. FIR filter is introduced to overcome the limitation in KF filter which has several parameters that difficult to be determined in a real application. In this work, three new estimation-based metaheuristic algorithms are introduced. The first algorithm is a single-agent-based algorithm, named Single-agent FIR optimizer (SAFIRO). The second algorithm is a multi-agent-based algorithm with synchronous update mechanism, named Multi-agent FIR optimizer (MAFIRO). The third algorithm is a multi-agent-based algorithm with asynchronous update mechanism, named Asynchronous FIR optimizer (AFIRO). SAFIRO differs from MAFIRO in term of the number of agents. Meanwhile, MAFIRO differs from AFIRO in terms of the iteration search strategy. These three algorithms are called in short as FIR optimizers (FIROs). Each agent in FIROs responsible for searching a solution by performing the measurement and estimation. During measurement, FIROs employ a random mutation of the best-so-far solution with local neighbourhood method to balance between the exploration and exploitation process. This measurement value is then used in the estimation to improve the solution iteratively. The performances of FIROs are tested by solving the CEC 2014 benchmark suite. The competencies of FIROs are statistically compared with four existing metaheuristic algorithms: the SKF, single-solution SKF (ssSKF), Particle swarm optimization (PSO), and Genetic algorithm (GA). Statistical analysis using the Friedman test and Holm post hoc test are performed to rank the performances of FIROs. Friedman test shows that SAFIRO has the highest rank, followed by MAFIRO, AFIRO, ssSKF, SKF, PSO, and GA. Holm post hoc test reveals SAFIRO performed significantly better than SKF, ssSKF, PSO, and GA. Whereas, both MAFIRO and AFIRO performed significantly better than PSO and GA, but equivalent to SKF and ssSKF. SAFIRO, MAFIRO, and AFIRO provide on par performances. However, SAFIRO can be regarded as the best algorithm with the highest ranking of Friedman and the highest number of best performances in solving the CEC 2014 benchmark suite. Findings show that the concept of UFIR filter is a good inspiration for metaheuristic algorithm. These newly estimation-based metaheuristic algorithms can offer promising results for solving optimization problems.

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LIST OF SYMBOLS

Y	Measurement of solution
X	Estimation of solution
***X**_best_so_far*	The best-so-far solution
N	Horizon length
β	Coefficient
d	Dimension for agent/s
D	Maximum dimension
δ	Step size/radius for local neighbourhood
X_{min}	The lower limit of search space
X_{max}	The upper limit of search space
F_f	Friedman Statistic
χ^2	Chi-square
α	Significant level
p-value	Probability value
z	Static value of Holm

LIST OF ABBREVIATIONS

ABC	Artificial bee colony
AFIRO	Asynchronous finite impulse response optimizer
CEC	Congress on evolutionary computation
DTI	Discrete time-invariant
DOF	Degree of freedom
EAs	Evolutionary algorithms
FES	Function evaluation
FIR	Finite impulse response
FIROs	Finite impulse response optimizers
Fn	Function
GA	Genetic algorithm
GSA	Gravitational search algorithm
GWO	Grey wolf optimizer
HKA	Heuristic Kalman algorithm
KF	Kalman filter
MAFIRO	Multi-agent finite impulse response optimizer
maxFES	Maximum function evaluation
NIA	Nature-inspired algorithm
no.	Number
PSO	Particle swarm optimization
SAFIRO	Single-agent finite impulse response optimizer
SA	Simulated annealing
SI	Swarm-inspired
SKF	Simulated Kalman filter
TS	Tabu Search
UFIR	Ultimate iterative unbiased finite impulse response
VNS	Variable neighborhood search

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