A DISCRETE SIMULATED KALMAN FILTER OPTIMIZER FOR COMBINATORIAL OPTIMIZATION PROBLEMS

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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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ABSTRAK

Masalah pengoptimuman kombinatorik ada di banyak bidang, termasuk penjagaan kesihatan, ekonomi, kejuruteraan, pembuatan, dan lain-lain. Penyelesaian untuk masalah pengoptimuman kombinatorik sering dinyatakan dalam bentuk permutasi, susunan, atau kombinasi elemen. Oleh kerana kepentingan praktikal masalah ini dalam isu dunia sebenar, banyak algoritma telah dicadangkan untuk menyelesaikannya. Algoritma ini secara khusus merujuk kepada algoritma yang beroperasi di ruang carian diskrit, yang sering dikenali sebagai algoritma kombinatorik. Jenis algoritma lain dipanggil algoritma numerik. Algoritma ini dibina khusus untuk mengatasi masalah pengoptimuman numerik. Dalam beberapa dekad terakhir ini, usaha penyelidikan yang signifikan telah dihabiskan untuk pengembangan algoritma numerik, terutama untuk menyelesaikan masalah kombinatorik. Berbagai kaedah telah diperkenalkan sebagai peluasan algoritma numerik untuk menyesuaikannya dengan ruang carian diskrit. Dalam kajian ini, algoritma kombinatorik baru yang dipanggil pengoptimuman penapis Kalman simulasi diskrit (DSKFO) dicadangkan untuk menyelesaikan masalah pengoptimuman kombinatorial. Algoritma baru ini diilhamkan oleh konsep penapis Kalman simulasi (SKF), yang merupakan algoritma pengoptimuman numerik. Oleh kerana keterbatasan algoritma asal yang hanya mampu beroperasi dalam ruang carian berterusan, algoritma yang dicadangkan menggunakan tafsiran baru yang menggabungkan mutasi dan jarak Hamming, membolehkan algoritma yang dicadangkan berfungsi di ruang carian diskrit. Dua jenis analisis kemudiannya digunakan untuk menilai algoritma yang dicadangkan. Pertama, algoritma DSKFO digunakan untuk menyelesaikan masalah jurujual mengembara (TSP), dan kemudian masa pelaksanaan algoritma diukur. Algoritma SKF sedia ada kemudiannya dibandingkan dengan penemuan algoritma DSKFO. DSKFO melakukan yang terpantas, memerlukan hanya 13 saat untuk menyelesaikan contoh TSP kecil, eil51, manakala DESKF, AMSKF, BSKF dan SEDESKF masing-masing memerlukan sekitar 36, 42, 34 dan 14 saat. Untuk menyelesaikan contoh TSP yang lebih besar, rl1889, DSKFO memerlukan 139 saat untuk melaksanakan satu larian, manakala DESKF, AMSKF, BSKF dan SEDESKF masing-masing memerlukan sekitar 1587, 1590, 2418 dan 208 saat. Untuk analisis kedua, prestasi algoritma yang dicadangkan dinilai menggunakan tiga masalah gabungan: masalah jurujual perjalanan (TSP), perancangan jujukan pemasangan (ASP), dan masalah penggerudian lubang. Hasilnya dibandingkan secara statistik dengan empat SKF kombinatorik yang diterbitkan sebelumnya: BSKF, AMSKF, DESKF, dan SEDESKF. DSKFO boleh dianggap sebagai algoritma terbaik untuk menyelesaikan TSP dan masalah penggerudian lubang, kerana ia mempunyai jumlah persembahan terbaik yang tertinggi. Untuk menyelesaikan ASP, DSKFO menduduki tempat ketiga, manakala AMSKF di tempat pertama, diikuti oleh DESKF di tempat kedua.

ABSTRACT

Combinatorial optimization problems are ubiquitous in many fields, including healthcare, economics, engineering, manufacturing, and others. A solution to a combinatorial optimization problem is frequently expressed in terms of a permutation, arrangement, or combination of elements. Due to the practical significance of this problem in real-world issues, numerous algorithms have been proposed to solve it. These algorithms specifically refer to those that operate in discrete search space, often known as combinatorial algorithms. Another type of algorithm is called numerical algorithms. These algorithms were built specifically to address numerical optimization problems. In the last few decades, significant research effort has been spent on the development of numerical algorithms, particularly for solving combinatorial problems. An example of a numerical algorithm is the simulated Kalman filter (SKF). Various method has been introduced as an extension of a numerical algorithm to adapt it to a discrete search space. There are currently three extensions to the SKF, resulting in three combinatorial algorithms: the binary SKF (BSKF), the distance evaluated SKF (DESKF), and the angle modulated SKF (AMSKF). However, these extensions may result in increased execution times for the algorithm. In this research, a new combinatorial algorithm named discrete simulated Kalman filter optimizer (DSKFO) is proposed to solve combinatorial optimization problem. This new algorithm is originated by the concept of the simulated Kalman filter (SKF). Due to the limitation of the SKF algorithm which only able to operate in continuous search space, the proposed algorithm makes use of a new interpretation that incorporates mutation and Hamming distance, allowing the proposed algorithm to function in discrete search space. In this research, three combinatorial problems namely the travelling salesman problem (TSP), assembly sequence planning (ASP), and the hole drilling proble are used to evaluate the proposed algorithm. Two types of analysis are used to evaluate the proposed algorithm. First, the DSKFO algorithm is used to solve the travelling salesman problem (TSP), and then the algorithm's execution time is measured. Existing SKF methods are then compared to the findings of the DSKFO algorithm. DSKFO performs the fastest, requiring just 13 seconds to solve a small TSP instance such as eil51, whereas DESKF, AMSKF, BSKF, and SEDESKF require around 36, 42, 34, and 14 seconds, respectively. To solve larger TSP instance such as rl1889, DSKFO requires 139 seconds to execute a single run, whereas DESKF, AMSKF, BSKF, and SEDESKF require around 1587, 1590, 2418, and 208 seconds, respectively. For the second analysis, the performance of the proposed method is evaluated using three combinatorial problems: the travelling salesman problem (TSP), the assembly sequence planning (ASP), and the hole drilling problem. The results are compared to four previously published combinatorial SKFs: the BSKF, the AMSKF, the DESKF, and the SEDESKF. The DSKFO may be considered the best algorithm for solving the TSP and hole drilling problem, as it has the highest number of best performances. For solving the ASP, the DSKFO ranked third, while the AMSKF came in first, followed by the DESKF in second.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

X	State estimation
t	Iteration
$t_{\max}$	Maximum iteration
n	Maximum number of agents
i	Current agent
D	Maximum dimension
d	Dimension for agents
X_{best}	The solution with best fitness
X_{true}	The best solution obtained so far
Z	Measurement
y	Measurement residual
H_d	Hamming distance
K	Kalman gain
P	Error covariance estimate
Q	Process noise
R	Measurement noise

LIST OF ABBREVIATIONS

ACO	Ant Colony Optimization
AMSKF	Angle Modulated Simulated Kalman Filter
ASP	Assembly Sequence Planning
ATSP	Asymmetric Travelling Salesman Problem
BSKF	Binary Simulated Kalman Filter
CVRP	Capacitated Vehicle Routing Problem
DESKF	Distance Evaluated Simulated Kalman Filter
DSKFO	Discrete Simulated Kalman Filter Optimizer
GA	Genetic Algorithm
HCP	Hamiltonian Cycle Problem
PCB	Printed Circuit Board
SA	Simulated Annealing
SEDESKF	Distance Evaluated Simulated Kalman Filter with State Encoded
SKF	Simulated Kalman Filter
SOP	Sequential Ordering Problem
TS	Tabu Search
TSP	Travelling Salesman Problem

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