HYBRIDIZING BAT ALGORITHM WITH LOCAL DISCRETE SEARCH FOR DYNAMIC TRAVELING SALESMAN PROBLEM

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DECLARATION

I hereby declare that this thesis, submitted to Universiti Malaysia Sabah as partial fulfillment of the requirements for the degree of bachelor computer science, has not been submitted to other university for any degree. I also certify that the works described herein is entirely my own, except for the quotations and summaries sources of which have been duly acknowledged.

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01 July 2015

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ABSTRACT

Dynamic optimization problems have become increasingly popular to solve in computational science. As real world problems are becoming more complex day by day, dynamic optimization problems have become an alternative platform for the application of heuristics methods. A higher class of heuristics, called metaheuristics has been a popular choice in solving optimization problems because of their ability to adapt to uncertainties and is not biased to any specific problem. One of the well-known classes of metaheuristics is swarm intelligence, inspired by the behavior of animal swarm in the nature. Ant Colony System and Particle Swarm Optimization are two instances of swarm intelligence. Bat algorithm on the other hand is one of the latest swarm intelligence proposed. It has been applied to many continuous and discrete problem domains. In this research, we will attempt to apply hybrid bat algorithm with local search to solve a well-established dynamic combinatorial problem, which is the dynamic traveling salesman problem (DTSP). The experiments included in this thesis are the parameter tuning of the bat algorithm parameters and then using those parameters to determine the optimal settings. The settings are then used in the bat algorithm framework to compare with other metaheuristics such as ACO and ACO with local search. As we have proposed two variants of the bat algorithm, we found that from the experiments, the second proposed variant which is the bat algorithm with natural frequency performs better compared to the bat algorithm with the original proposed frequency across all benchmarks and dynamic test cases. However, the proposed algorithms were still unable to outperform the conventional ACO and hybridized ACO algorithms. Nevertheless, their performances are enhanced by the hybridization of the 2-Opt local search.

ABSTRAK

Masalah pengoptimuman dinamik merupakan masalah yang semakin popular untuk diselesaikan di dalam bidang pengkomputeran sains. Masalah dunia sebenar yang semakin kompleks telah menjadikan masalah pengkomputeran sebagai platform alternatif untuk pengaplikasian kaedah heuristik. Kaedah heuristik yang lebih sofistikated, juga dikenali sabagai metaheuristik merupakan pilihan yang popular untuk menyelesaikan masalah pengoptimuman dinamik disebabkan kemampuan mereka untuk mengadaptasi kepada ketidaktentuan dan tidak menyebelahi mana-mana masalah yang spesifik. Salah satu kelas metaheuristik yang terkenal adalah kecerdasan kawanan, yang diinspirasikan daripada perlakuan kawanan haiwan semula jadi. Antara kecerdasan kawanan yang telah dicadangkan adalah sistem koloni semut dan pengoptimuman kawanan partikel. Algoritma kelawar pula merupakan salah satu kecerdasan kawanan yang telah dicadangkan baru-baru ini. Ia telah diaplikasikan di dalam pelbagai masalah domain diskret dan lanjutan. Di dalam kajian ini, kami akan cuba untuk mengaplikasi algoritma kelawar dengan strategi carian tempatan untuk menyelesaikan masalah kombinatorik dinamik iaitu masalah perjalanan jurujual dinamik. Eksperimen yang telah dijalankan termasuklah pengoptimuman parameter algoritma kelawar dan perbandingan antara nilai optima yang diperolehi dari algoritma kelawar yang dicadangkan, sistem koloni semut dan sistem koloni semut yang telah dihibridasikan dengan strategi carian tempatan. Kita telah mencadangkan dua jenis algoritma kelawar dan hasil daripada eksperimen eksperimen yang dilakukan, kita mendapati bahawa algoritma jenis kedua mempunyai nilai optima yang lebih baik untuk setiap kes perjalanan. Walaupun begitu, prestasi algoritma yang dicadangkan kurang memberangsangkan kerana nilai optima yang diperoleh kurang jika dibandingkan dengan algoritma semut and versi semut yang dihibridasikan dengan carian tempatan. Namun, ini membuktikan bahawa sesuatu algoritma itu dapat dipertingkatkan dari segi efisien melalui pernambahan strategi carian tempatan.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

GLOSSARY OF RESEARCH KEY TERMS AND PHRASES

Benchmark problem	A standardized and specific problem for assessing the performance of algorithms
Combinatorial	Related to finite discrete domain variables
Continuous	Related to varying continuously real-valued variables
Domain	Defines the scope where the problem occurs
Dynamic	A consistent change in state over a period of time
Evolutionary Computation	Subfield of artificial intelligence that involves combinatorial and continuous optimization problems
Non-polynomial	Is the set of decision problems where the "yes" instances can be accepted in polynomial time by a deterministic Turing machine
Optimization problem	Problem of finding best solution from all feasible solutions
Problem instances	A set of computational problems that usually falls under the same category
Static	A fixed and unchanged state over a period of time

LIST OF ABBREVIATIONS

ABC - Artificial Bee Colony

ACO - Ant Colony Optimization

ACS - Ant Colony System

AES - Agent-based Evolutionary Search

ALS - Annealing with Learning Scheme

APF - Annealed Particle Filter

ASTP-GA - Asymmetric Traveling Salesman Genetic Algorithm

BA - Bat Algorithm

BAM - Bat Algorithm with Mutation

BAST - Bat Algorithm based on Scheduling Tool

BBA - Binary Bat Algorithm

BBO - Biogeograph-based Optimization

CBA - Chaotic Bat Algorithm

CS - Cuckoo Search

CS-GRASP - Cuckoo Search with Greedy Randomized Adaptive Search Procedure

CVRP - Capacitated Vehicle Routing Problem

CWS - Clark and Wright Savings

DABA - Directed Artificial Bat Algorithm

DBA - Discrete Bat Algorithm

DBG - Dynamic Benchmark Generator

DCOP - Dynamic Combinatorial Optimization Problem

DE - Differential Evolution

DIOEA - Dynamic Inver-over Evolutionary Algorithm

DOP - Dynamic Optimization Problem

DPSO - Dynamic Particle Swarm Optimization

DTSP - Dynamic Traveling Salesman Problem

EC - Evolutionary Computing

FA - Firefly Algorithm

FLBA - Fuzzy Logic Bat Algorithm

GA - Genetic Algorithm

GRASP - Greedy Randomized Adaptive Search Procedure

GSA - Gravitational Search Algorithm

HBA - Hybrid Bat Algorithm

HBA-PR - Hybridized Bat Algorithm with Path Relinking

HS - Harmony Search

IBA - Improved Bat Algorithm

IEEE - Institute of Electrical and Electronics Engineers

ILS - Iterated Local Search

MMRE - Mean Magnitude of Relative Error

MOBA - Multi-Objective Bat Algorithm

NP - Non-deterministic Polynomial time

PBIL - Population-based Incremental Learning

PF - Particle Filter

PGA - Parallel Genetic Algorithm

PSO - Particle Swarm Optimization

RFD - River Formation Dynamic

SA - Simulated Annealing

SD - Standard Deviation

SGA - Simple Genetic Algorithm

SOP - Static Optimization Problem

SSPF - Scatter Search Particle Filter

SR-GCWS - Simulation via Routing in the Generalized Clark and Wright Savings

STSP-GA - Symmetric Traveling Salesman Problem Genetic Algorithm

TLBO - Teaching and Learning Based Optimization

TS - Tabu Search

TSP - Traveling Salesman Problem

TSPLIB - Library of sample instances for TSP (and related) instances

XOR - Exclusive OR

LIST OF MATHEMATICAL SYMBOLS

$\sum$ - Sum of

$\neq$ - Not equal to

$=$ - Equal to

$>$ - Greater than

$<$ - Less than

$\leq$ - Less greater than or equal to

$\in$ - Belong to

O - Big O notation

$\approx$ - Rounded to

% - Percentage of

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter will examine the research topic which is hybridizing bat algorithm with discrete local search for solving dynamic traveling salesman problem (DTSP) from different aspects. The aspects include introduction to the problem background, problem statement, hypothesis, objectives and scope of research. In problem background, we will briefly explain the Traveling Salesman Problem (TSP), DTSP and why they remain difficult to solve till these days. TSP and DTSP will also be defined in this section. In problem statement section, we will briefly justify the use of metaheuristics method especially the bat algorithm in solving DTSP. For hypothesis, we will state the expected outcome for implementing bat algorithm with local discrete search in DTSP. We will further state the objectives and the scope for the research before settling on the organization of this report.

1.2 Problem Background

There are many core open problems still exist in the computational complexity theory that remain challengingly unsolved. One of the problems is non-polynomial (NP) hard problems where no efficient algorithm is known as they cannot be solved in polynomial time. In this context, Traveling Salesman Problem (TSP) would be the most famous case of NP hard problem. Till these days, TSP remains the most intensively studied problem in computational mathematics. The main objective for TSP can be described as simple as finding the shortest possible route while traveling exactly once across a set of cities that consists of certain distances and eventually returning to the starting city with minimal total distance. The solution space for TSP problem can be extremely large depending on the number of cities. In other words, it increases exponentially with the number of cities. Variants of TSP have also existed which the most crucial being the Dynamic Traveling Salesman Problem (DTSP). DTSP is basically the generalization of classic TSP where changes can be introduced by adding or deleting cities, swapping location of cities or changing the value of pairwise distances. After changes are introduced, the salesman needs to re-plan his route. Many real world optimization problems are dynamic optimization problems (DOPs) where changes may occur over time regarding the objective function, decision variable, constraints and others. Therefore, DTSP is one of the useful benchmark problems that can be used to emulate the real dynamic traffic scenario. For example, exchangeable cities and traffic factors where the global optimum value is unknown during the environment.

1.2.1 Definition of Traveling Salesman Problem (TSP)

In order to create an algorithm framework for DTSP, we have to define TSP first. It can be described as follows: Given a collection of cities and pairwise distances of the cities, we need to find the shortest path that starts from one city and visits each of the other cities once and only once before returning to the starting city. The main objective is to minimize the sum of distances used to visit the entire tour. Usually the problem is represented by a fully connected weighted graph G = (N, A), where N = {0, … , n} is a set of nodes and $A = \{(i, j) : i \neq j\}$ is a set of arcs. The collection of cities is represented by the set N and the connections between them by the set A. Each connection (i, j) is associated with a non-negative value d_{ij} which represents the distance between cities i and j. TSP can be formally described as follows:

$$f(x) = min \sum_{i=0}^{n} \sum_{j=0}^{n} d_{ij}\ \psi_{ij}$$

Subject to:

$$\psi_{ij} = \begin{cases} 1, \text{if } (i,j) \text{is used in the tour} \\ 0, \quad \text{otherwise} \end{cases}$$

Where $\psi_{ij} \in \{0, 1\}$, n is the number of the cities and d_{ij} is the distance between city i and j. Each city $i \in N$ has a location defined by (x, y) and each connection $(i, j) \in A$ is associated with a non-negative distance d_{ij} .

1.2.2 Definition of DTSP

In this paper, the DTSP functions as the platform to change any static instances for conventional TSP into a dynamic environment where the fitness landscape remains unchanged but the algorithm will be inclined to be shifted to search for different parts of fitness landscape between time intervals. Since the encoding of the problems changes, the DTSP can be defined as:

$$D(t) = \{d_{ij}\ (t)\}_{n(t) \times n(t)}$$

Where d_{ij}(t) is the cost from city i and j, t is the real world time. The number of cities $n(t)$ and the cost matrix are time dependent.

1.3 Problem Statement

Traditional method such as brute force search is infeasible to be applied to solve TSP. Therefore, the use of heuristics and exact methods are widely accepted instead to solve TSP. A more versatile heuristics, which is the metaheuristics has gained popularity in recent years due to its flexibility which can be used as the black-box approach. Nevertheless, applying metaheuristics method can solve TSP or DTSP more efficiently in terms of the quality of the optimal solutions. Through this research, we will implement a relatively new metaheuristics, bat algorithm with local search to solve DTSP, considering its potential in various fields of optimization problems.

1.4 Hypothesis

Hybridization of bat algorithm with local search strategy will improve the chances of finding a good quality of optimal solution. The quality of the optimal solution in this context shall be based on comparison of optimal solutions obtained in the hybridized bat algorithms and other metaheuristics methods.

1.5 Objectives of Research

a. To design and implement proposed an improved metaheuristic algorithm which is the hybridized bat algorithm with local discrete search to solve DTSP.

b. To deploy and test hybridized bat algorithm with local discrete search to solve DTSP.

c. To verify the performance of hybridized bat algorithm with local discrete search by direct comparison with other heuristics and metaheuristics for solving DTSP.

1.6 Scope of Research

Our research will focus on the application of recently developed nature inspired algorithm which is bat algorithm, which will be hybridized with local discrete search in solving traveling salesman problem with a dynamic environment (as the benchmark problem) only and not solving other optimization problems. In order to demonstrate the effectiveness of the algorithm, several well known problem instances have been selected from the IEEE competition website in regard of the benchmark problem (Mavrovouniotis, Li, Yang and Yao, 2013). The problem instances consist of seven cities, namely eil51, kroA100, kroA150, kroA200, lin318, and pr439. In between testing and performing the algorithm to solve DTSP, some research might

REFERENCES

Akhtar, S., Ahmad, A. R. and E. M. Abdel-Rahman. 2012. "A metaheurisic bat-inspired algorithm for full body human pose estimation", in: *Ninth Conference on Computer and Robot Vision*, pp. 369–375.

Blum, C., and Roli, A. 2003. "Metaheuristics in combinatorial optimization: Overview and conceptual comparison." *ACM Computing Surveys (CSUR)*, *35*(3), pp. 268-308.

Bora, T. C., Coelho, L. D. S. and Lebensztajn, L. 2012. "Bat-inspired optimization approach for the brushless DC wheel motor problem", in *Magnetics, IEEE Transactions on*, *48*(2), pp. 947-950.

Boryczka, U. and Strąk, Ł. 2013. "Efficient DPSO Neighbourhood for Dynamic Traveling Salesman Problem", in *Badica et al.,editor*, ICCCI, LNAI 8083, pp. 721-730.

Branke, J. 1999. "Memory enhanced evolutionary algorithms for changing optimization problems", in *Evolutionary Computation (CEC), 1999 IEEE* , pp. 1875–1882.

Cantú-Paz, E. 1995. "A summary of research on parallel genetic algorithms."

Dorigo, M., & Gambardella, L. M. 1997. "Ant colony system: a cooperative learning approach to the traveling salesman problem." *Evolutionary Computation, IEEE Transactions on*, *1*(1), pp. 53-66.

Eyckelhof, C.J. 2001. "Ant System for Dynamic Problem, the TSP Case – Ant Caught in a Traffic Jam", Master's thesis, Unversity of Twente, the Netherlands.

Fister Jr, I., Fister, D., and Yang, X. S. 2013. ”A hybrid bat algorithm.”, *arXiv preprint arXiv:1303.6310*.

Flood M. M. 1956. "The Traveling-Salesman Problem," *Oper. Res.* 4, pp. 61-75.

Fu, H., Lewis, P. R., Sendhoff, B., Tang, K., & Yao, X. 2014. “What are dynamic optimization problems?” in *Evolutionary Computation (CEC), 2014 IEEE,* pp. 1550-1557.

Gandomi, A. H., Yang, X. S., Alavi, A.H., and Talatahari, S. 2013. “Bat algorithm for constrained optimization tasks”, *Neural Computing and Applications*, vol. 22, no. 6, pp. 1239–1255.

Garey, M. and Johnson, D. 1979. “*Computers and Intractability: A Guide to the Theory of NP-Completeness”.* W. H. Freeman and Company, San Fransico.

Glover, F. 1989. Tabu search-part I. *ORSA Journal on computing*, pp. 190-206.

Glover, F. 1996. “Tabu search and adaptive memory programming advances, applications and challenges”, in *Interfaces in Computer Science and Operations Research*, R. S. Barr,R.V.Helgason, and J. L. Kennington, Eds., pp. 1–75.

Liu, G., Huang, H., Wang, S. and Chen, Z. 2012. “An Improved Bat Algorithm with Doppler Effect for Stochastic Optimization”,in *International Journal of Digital Content Technology & its Applications*.

Guntsch, M., Branke, J., Middendorf, M. and Schemck, H. 2000. “ACO Strategies for Dynamic TSP”, in *M.Dorrigo et al.,editor*, *Abstract Proceedings of ANTS’2000*, pp. 59-62.

Guntsch, M. and Middendorf, M. 2001. "Pheromone Modification Strategies for Ant Algorithms Applied to Dynamic TSP", in *Applications of Evolutionary Computing*, Lecture Notes in Computer Science, Vol.2037, pp. 213-220.

Guntsch, M., Middendorf, M. and Schemck, H. 2001. "An Ant Colony Optimization Approach to Dynamic TSP", in *Proceedings of the GECCO 2001*, pp. 860-867.

Gupta, R., Chaudhary, N., & Pal, S. K. 2014. "Hybrid model to improve Bat algorithm performance", in *Advances in Computing, Communications and Informatics (ICACCI, 2014 International Conference on IEEE,* pp. 1967-1970.

Lemma, T. A., & Bin Mohd Hashim, F. 2011. "Use of fuzzy systems and bat algorithm for exergy modeling in a gas turbine generator", In *Humanities, Science and Engineering (CHUSER), 2011 IEEE Colloquium on* IEEE, pp. 305-310.

Lin, J. H., Chou, C. W., Yang, C. H., & Tsai, H. L. 2012. " A chaotic Levy flight bat algorithm for parameter estimation in nonlinear dynamic biological systems", Journal *Computer and Information Technology*, *2*(2), pp. 56-63.

Lo, C. C., & Hsu, C. C. 1998. "An annealing framework with learning memory.", *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, *28*(5), pp. 648-661.

Luo, Q., Zhou, Y., Xie, J., Ma, M., and Li, L. 2014. "Discrete Bat Algorithm for Optimal Problem of Permutation Flow Shop Scheduling", *The Scientific World Journal*.

Mavrovouniotis, M., Yang, S., and Yao, X. 2012. "A benchmark generator for dynamic permutation-encoded problems", in *Parallel Problem Solving from Nature-PPSN XII* Springer Berlin Heidelberg. pp. 508-517.

Mavrovouniotis, M., Li, C., Yang, S. and Yao, X. 2013. “Benchmark Generator for the IEEE WCCI-2014 Competition for Dynamic Optimization Problems”, in *IEEE World Congress on Computational Intelligence*, pp. 1-5.

Menger, K. 1930. *Ergebnisse eines Kolloquiums* 3, pp. 11-12.

Morrison, R.W., De Jong, K.A. 1999. “A test problem generator for non-stationary environments”, in *Evolutionary Computation (CEC), 1999 IEEE,* pp. 2047–2053.

Musikapun, P. and Pongcharoen, P. 2012. “Solving multi-stage multi-machine multi-product scheduling problem using bat algorithm”, *Department of Industrial Engineering, Faculty of Engineering, Naresuan University, Thailand*.

Nakamura, R. Y., Pereira, L. A., Costa, K. A., Rodrigues, D., Papa, J. P., and Yang, X. S. 2012. “BBA: A binary bat algorithm for feature selection”, in *Graphics, Patterns and Images (SIBGRAPI), 2012 25th SIBGRAPI Conference on IEEE,* pp. 291-297.

Pantrigo, J. J., and Duarte, A. 2013. “Low-Level Hybridization of Scatter Search and Particle Filter for Dynamic TSP Solving”, in *Metaheuristics for Dynamic Optimization.* Springer Berlin Heidelberg, pp. 291-308.

Psaraftis, H.N. 1988. “Dynamic Vehicle Routing Problem”, in *Vehicle Routing: Methods and Studies,* Elsevier Science Publishers (B. V.) (North Holland), pp. 223-248.

Rabanal, P., Rodríguez, I., and Rubio, F. 2008. “Solving dynamic TSP by using river formation dynamics”, in *Natural Computation, 2008. ICNC'08. Fourth International Conference on IEEE*, Vol. 1, pp. 246-250.

Ramesh, B., Mohan, V. C. J. and Reddy, V. C. V. 2013. "Application of bat algorithm for combined economic load and emission dispatch", *International Journal of Electrical Engineering and Telecommunications*, Vol. 2, No. 1, pp. 1–9.

Rekaby, A. 2013. "Directed Artificial Bat Algorithm: a new bio-inspired algorithm", in *International Conference on advances in Computing, Communications and Informatics (ICACCI),* pp. 1241-1246.

Rohlfshagen, P. and Yao, X. 2008. "Attributes of dynamic combinatorial optimisation", *Proceeding of the 10th International Conference on Parallel Problem Solving From Nature, PPSN'08*, LNCS 5361, pp. 442–451.

Rohlfshagen, P. and Yao, X. 2011. " Dynamic combinatorial optimisation problems: an analysis of the subset sum problem.", *Soft Computing*, **15**, pp. 1723–1734

Savsani, P., Jhala, R. L., and Savsani, V. J. 2014. "Comparative Study of Different Metaheuristics for the Trajectory Planning of a Robotic Arm", *IEEE*.

Wang, D. Z. and Liu, S. X. 2010. "An agent-based evolutionary search for dynamic traveling salesman problem", in *2010 WASE International Conference on Information Engineering,* pp. 111-114.

Wang, G., Guo, L., Duan, H., Liu, L., and Wang, H. 2012. "A bat algorithm with mutation for UCAV path planning", *The Scientific World Journal*.

Wang, G. and Guo, L. 2013. "A novel hybrid bat algorithm with harmony search for global numerical optimization", *Journal of Applied Mathematics.*

Yang, S. 2003. "Non-stationary problem optimization using the primal-dual genetic algorithm", in *Evolutionary Computation (CEC), 2003 IEEE,* pp. 2246–2253.

Yang, X.S. 2013. “Bat algorithm: literature review and applications”, *International Journal of Bio-Inspired Computation*, Vol. 5, No. 3, pp. 141–149.

Yang, X. S. 2010. “A New Metaheuristic Bat-Inspired Algorithm”, in *Nature Inspired Cooperative Strategies for Optimization* (NICSO 2010) (Eds. J. R. Gonzalez et al.), SCI 284, pp. 65-74.

Yang, X. S. 2011. “Bat algorithm for multi-objective optimisation.” *International Journal of Bio-Inspired Computation*, pp. 267-274.

Yang, S., Jiang, Y. and Nguyen, T.T. 2012. “Metaheuristics for Dynamic Combinatorial Optimization Problem”, in *IMA Journal of Management Mathematics,* pp. 1-29.

Yang, X. S. and Gandomi, A. H. 2012. “Bat algorithm: a novel approach for global engineering optimization”, *Engineering Computations*, vol. 29, pp. 464–483.

Yang, X.S. 2013. “Bat algorithm and cuckoo search: a tutorial”, in *Evolutionary Computation and Metaheuristics*, SCI 427, pp. 421-434.

Yazdani, D., Akbarzadeh-Totonchi, M. R., Nasiri, B., & Meybodi, M. R. 2012. “A new artificial fish swarm algorithm for dynamic optimization problems”, in *Evolutionary Computation (CEC), 2012 IEEE,* pp. 1-8.

Yilmaz, S., & Kucuksille, E. U. 2013. “Improved bat algorithm (IBA) on continuous optimization problems. *Lecture Notes on Software Engineering*, *1*(3), pp. 279-283.

Zhong, W. L., Zhang, J., & Chen, W. N. 2007. “A novel discrete particle swarm optimization to solve traveling salesman problem.” in *Evolutionary Computation (CEC), 2007 IEEE,* pp. 3283-3287.

Zhou, A. M., Kang, L. S. and Yan, Z.Y. 2003. "Solving Dynamic TSP with Evolutionary Approach in Real Time", in *Evolutionary Computation (CEC), 2013 IEEE,* pp. 951 – 957.

Zhou, Y., Xie, J. and Zheng, H. 2013. "A Hybrid Bat Algorithm with Path Relinking for Capacitated Vehicle Routing Problem", in *Mathematical Problems in Engineering*.