A GENETIC SIMPLIFIED SWARM ALGORITHM
FOR OPTIMIZING
n- CITIES OPEN LOOP TRAVELLING SALESMAN PROBLEM

CHIENG HOCK HUNG

A thesis submitted in
fulfillment of the requirement for the award of the
Degree of Master of Information Technology

Faculty of Computer Science and Information Technology
Universiti Tun Hussein Onn Malaysia

JANUARY 2016

DEDICATION

Dedicated to the Lord Almighty God;
Heavenly Father, Jesus Christ and Holy Spirit.
Papa, Mama, Lydia, Debrorah, and Hope's family.

ACKNOWLEDGEMENT

Firstly, I would like to give thanks to my best friend, Heavenly Father, for His unconditional love and favors in my life. He is the source of my strength, wisdom and knowledge. He has empowered and granted me strength to soar on wing like eagle above the raging sea.

Secondly, I would like to thanks my supervisor, Dr Noorhaniza Wahid as well. She was the direct contributor for this work. I would like to express my thankfulness to her from the bottom of my heart. Her understanding, wisdom and personal experiences have provided a good basis for this present thesis. She always guided and pointing me to the right direction toward fulfillment of this project. Other than that, she is also a kind person that always shares her life experiences to encourage and inspire me in this journey of research.

I am grateful to my beloved parents and sisters for their support, provision, care and love. They were always encouraged me and even prayed a lot for me along my Master research's journey.

In addition, I would like to thanks Szakif Enterprize for providing me the best service in thesis proofreading.

Lastly, my special gratitude is due to my brothers and sisters in Hope Life Group. I wish to express my deepest and sincere thanks to them who had accompanied me with prayers, love, concern, support and advice over the past whole two years.

This research project would not have been completed without the help of many including the writing of others, who are acknowledged within the reference section.

Thank you!

PUBLICATION

Chieng, H. H., and Wahid, N. (2014). *A Performance Comparison of Genetic Algorithm's Mutation Operators in n-Cities Open Loop Travelling Salesman Problem*. Recent Advances on Soft Computing and Data Mining pp. 89-97. Springer International Publishing. (Indexed by ISI, DBLP, El-Compendex, Scopus).

ABSTRACT

Open Loop Travelling Salesman Problem (OTSP) is one of the extension of Travelling Salesman Problem (TSP) that finding a shortest tour of a number of cities by visiting each city exactly once and do not returning to the starting city. In the past, TSP and OTSP has been applied in various vehicle routing systems to optimize the route distance. However, in real-life scenario such as transportation problem does not seem similar as pictured in OTSP whereby do not all cities are required to be visited but simply restrain to several number of *n* cities. Therefore, a new problem called *n*-Cities Open Loop Travelling Salesman Problem (*n*OTSP) is proposed. In the past, Genetic Algorithm (GA) is a popular algorithm that used to solve TSPs. However, GA often suffers from premature convergence due to the difficulty in preventing the loss of genetic diversity in the population. Therefore, Genetic Simplified Swarm Algorithm (GSSA) is proposed in this study to overcome the drawback of GA. GSSA is an improved GA based algorithm with Simplified Swarm Optimization (SSO) algorithm's characteristic named Solution Update Mechanism (SUM). The SUM is modified by embedding three GA mutation operators. Then, GSSA is used to optimize *n*OTSP in terms of finding the shortest tour. Later, the performance of GSSA is compared with GA without crossover operator (GA-XX) and GA with one-point crossover operator (GA-1X). Performance of the proposed algorithm is measured based on the shortest distance and average shortest distance found by the algorithm. Meanwhile, an investigation on influence of population size towards algorithm was also studied. The experiment results show that GSSA can discover shorter tour than GA-XX and GA-1X. Nevertheless, the study also found that most of the good solutions are discovered in the larger population sizes from 3000 to 5000.

ABSTRAK

Open Loop Travelling Salesman Problem (OTSP) merupakan salah satu lanjutan kepada *Travelling Salesman Problem* (TSP) yang mencari laluan tersingkat dengan syarat hanya mengunjungi setiap bandar sekali sahaja dan tidak kembali ke bandar di mana perjalanan bermula. Namun begitu, dalam situasi sebenar contohnya masalah pengangkutan, ia tidak sama dengan OTSP. Kebanyakan kenderaan tidak mengunjungi setiap bandar, tetapi hanya terhad kepada sejumlah bandar *n* sahaja. Oleh itu, masalah baru yang dinamakan *n-Cities Open Loop Travelling Salesman Problem* (*n*OTSP) dicadangkan di dalam kajian ini. Pada masa lalu, *Genetic Algorithm* (GA) merupakan algoritma yang popular untuk menyelesaikan masalah TSP. Namun, GA sering mengalami masalah penumpuan pra-matang yang disebabkan oleh kesukaran untuk mencegah kehilangan kepelbagaian genetik. Oleh itu, satu algoritma yang dinamakan *Genetic Simplified Swarm Algorithm* (GSSA) dicadangkan untuk mengatasi kelemahan GA di dalam kajian ini. GSSA merupakan penambahbaikan GA yang mengandungi ciri-ciri algoritma *Simplified Swarm Optimization* (SSO). Ciri-ciri ini dikenali sebagai *Solution Update Mechanism* (SUM). SUM diubahsuai terlebih dahulu dengan menerapkan tiga operator mutasi GA. Seterusnya, GSSA dilaksanakan untuk mengoptimumkan *n*OTSP dari segi pencarian laluan yang tersingkat. Di samping itu, prestasi GSSA akan dibandingkan dengan prestasi GA tanpa operator *crossover* (GA-XX) dan GA yang mengandungi operator *one-point crossover* (GA-1X). Prestasi algoritma dinilai melalui jarak terpendek dan purata jarak terpendek yang diperolehi. Selain itu, kajian ke atas pengaruh saiz populasi terhadap algoritma juga dikaji. Keputusan kajian jelas menunjukkan bahawa GSSA berupaya untuk meneroka laluan yang lebih pendek berbanding GA-XX dan GA-1X. Di samping itu, kajian ini juga mendapati bahawa kebanyakan penyelesaian yang baik ditemui dalam saiz populasi yang lebih besar iaitu dari 3000 hingga 5000.

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LIST OF ALGORITHMS

LIST OF SYMBOLS AND ABBREVIATIONS

d	-	Distance
D	-	Variable domain
E	-	Edge
$f(x)$	-	Function of x
G	-	Graph
$gbest$	-	Global best
$gloFit$	-	Global fitness
i	-	Location of the particle in PSO
Inf	-	Infinity
$maxFit$	-	Maximum fitness value
$MaxGen$	-	Maximum generation
m	-	Number of total given cities
min	-	Smallest elements in array (MATLAB SYNTAX)
n	-	Number of visited cities
$newFit$	-	New fitness
p	-	Population size
$pbest$	-	Local best
$randperm$	-	Random permutation (MATLAB SYNTAX)
$rand$	-	Random (MATLAB SYNTAX)
s	-	Optimal solution
S	-	Global optimal solution
t	-	Time
V	-	Vertex
w	-	Inertial weight
$zeros$	-	Create array of all zeros (MATLAB SYNTAX)
α	-	Personal experience
β	-	Population experience

$\mathbb{R}$	-	Real number
v_i^t	-	Particle velocity in PSO
x_i^t	-	Particle position in PSO
c_i	-	Constraints
C_w, C_p, C_g	-	Predetermined constants
ACO	-	Ant Colony Optmization
ABC	-	Artificial Bee Colony
AI	-	Artificial Intelligent
AIS	-	Artificial Immune System
AS	-	Ant System
BF	-	Bacterial Foraging
CSO	-	Cat Swarm Optimization
EA	-	Evolutionary Algorithm
DPfGA	-	Distributed Parameter Free Genetic Algorithm
DPSO	-	Discrete Particle Swarm Optimization
GA	-	Genetic Algorithm
GA-1X	-	Genetic Algorithm with one-point crossover operator
GA-GSTM	-	Greedy Sub Tour Mutation operator
GA-XX	-	Genetic Algorithm without crossover operator
GNSS	-	Global Navigation Satellite System
GSO	-	Glowworm Swarm Optimization
GSSA	-	Genetic Simplified Swarm Algorithm
*n*OTSP	-	*n*-Cities Open Loop Travelling Salesman Problem
OTSP	-	Open Loop Travelling Salesman Problem
PSO	-	Particle Swarm Optimization
SA	-	Simulated Annealing
SUM	-	Solution Update Mechanism
TS	-	Tabu Search
TSP	-	Travelling Salesman Problem

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Road networks play a significant role for the economics growth and development of a city. Road networks can be described as the equivalent of the veins in the human body, and the vehicles are the blood cells that carry the nutrition from one part of the body to the another part. In the reality of transportation, it is important for the transportation system to identify the best route to navigate the drivers to their destination. For example, an emergency evacuation unit's transportation fleet such as ambulances and firetrucks are required to reach the emergency site quickly by using shortest tour for evacuation and emergency purposes. The other example such as the Global Positioning System (GPS) that often used by the drivers in order to navigate and show them the shortest route to an unfamiliar place. Until today, many researches are still continuously improving the real-world vehicles routing system in order to provide more effective and efficient route to travel (Toth & Vigo, 2014; Gomez & Salhi, 2014; Royo *et al.*, 2015). One of the common vehicles routing problem in computer science is Travelling Salesman Problem (TSP) (El-Gharably *et al.*, 2013). This problem is used to simulate and solve routing problems.

TSP is a well-known and important combinatorial optimization problem (Ausiello *et al.*, 2012). It was first introduced by a mathematician from Ireland named William Rowan Hamilton and a British mathematician, named Thomas Penyngton Kirkman in the 1800s (Matai *et al.*, 2010). Later, the problem was formulated by Karl Menger in 1930 (Maredia, 2010). TSP is closely related to the Hamiltonian path problem, where it devotes a path in an undirected or directed graph that visits all the vertices exactly once (Abdoun & Abouchabaka, 2012). However, the idea of TSP is in regard to a salesman who supposed to travel by visiting all the given cities exactly once and returns to the city he started, with the shortest route.

Despite TSP is devoted to a complete closed Hamilton path, TSP generally can be divided into two categories, which are Closed Loop TSP and Open Loop TSP (OTSP). Closed Loop TSP is similar with the ordinary TSP, while OTSP has a slight difference when compared with TSP. The difference between OTSP and TSP is that it has different starting and ending points. In other words, salesman in the OTSP travels to each city exactly once by departing from one city but does not return to the city where he departed.

However, in reality, today's transportation issue is not exactly similar to what has been described in the TSP and OTSP. In contrary, the numerous of transportation issues are not related with "visit all the given cities", in fact, simply visiting certain number of cities rather than all the given cities which can lead to shortest tour distance. For example, in the logistics of merchandise delivery services, the drivers are required to plan the route by departing from the depot to the destination without required to visit all the cities along the route, yet, they are restrained to a certain numbers of cities for cost and time saving purposes.

Inspired from this issue, this research proposes a new extension of OTSP called *n*-Cities Open Loop Travelling Salesman Problem (*n*OTSP). The *n*OTSP can be illustrated through the scenario where a salesman is given a set of cities, but only required to visit a certain number of cities rather than all the cities in a minimum tour.

Over the past decades, many algorithms have been successfully applied to a wide range of combinatorial problems including TSPs. These algorithms include Tabu Search (TS) (Pedro *et al.*, 2013), Genetic Algorithm (GA) (Nagata & Soler, 2012) and Simulated Annealing (SA) (Wang *et al.*, 2013). Among them, GA is one of the most popular algorithms that used to solve permutation problems such as TSP (Ahmed, 2010). In GA, it generates a set of possible solutions through permutation of the genes. Hence, the solutions of TSP can also be easily represented as permutation of genes in the GA.

Besides GA, swarm-based algorithms also have been used to solve high complexity problems such TSPs. The example of swam-based algorithms have been use to solve TSPs in the past are Particle Swarm Optimization (PSO) (Eberhart & Kennedy, 1995), Ant Colony Optimization (ACO) (Colorni *et al.*,1992), Artificial

Bee Colony algorithm (ABC) (Karaboga, 2005) and Bat algorithm (BA) (Yang, 2010).

Recently, another new swarm-based algorithm that has been proposed was named Simplified Swarm Algorithm (SSO) (Chung & Wahid, 2012). SSO is the variant of PSO. In the past, SSO is used to solve the classification problem and has shown good performances. One of the reasons for its success is due to its special characteristic, known as the comparison strategy. The purpose of this comparison strategy is to update the global best (*gbest*) solution once a better solution is found.

Therefore this research proposes a GA based algorithm by adopting the characteristic of SSO in GA. Hence, this algorithm is named as Genetic Simplified Swarm Algorithm (GSSA). Later, the algorithm is used to optimize the *n*OTSP.

1.2 Problem Statement

TSP is a well-known combinatorial problem that is often used to model vehicles' routing issues such as in transportation scenarios. However, it is realized that the problems are not exactly similar as what has been pictured in TSP and OTSP. Conversely, the vehicle may only travel from the starting point to the ending point by visiting only a certain number of cities with minimum total travelling distance. For example, a logistic services company which is in charge of delivering goods from the depot to the destination by visiting only several numbers of cities, without passing through all the cities along the route to keep the minimum distance. In order to tackle this issue, this research models a variant of TSP called *n*OTSP.

In recently year, nature-inspired algorithms are commonly used and are popular in the context of optimization. Among them, GA has been highlighted to have good performances in solving many combinatorial problems such as TSP (Ahmed, 2010; Dwivedi *et al.*, 2012; Bahaabadi *et al.*, 2012). However, GA often suffers from the tendency to converge towards local optima or also known as prematurely converge (Vashisht, 2013). Genetic diversity is often considered as the primary reason for prematurely convergence in GA (Gupta & Ghafir, 2012). The premature convergence is generally due to insufficiency of the diversity within the population (Malik & Wadhwa, 2014). Therefore, to ensure the adequate of genetic diversity is crucial for the algorithm to avoid them to be trapped at the local optima (Gupta & Ghafir, 2012; Malik & Wadhwa, 2014).

To overcome the drawback, this research proposes an improved GA with SSO's characteristic in order to prevent the loss of genetic diversity and improve the solutions.

1.3 Objectives of the Study

The objectives of this research are:

i. to propose a new extension of OTSP variant named *n*-Cities Open Loop Travelling Salesman Problem (*n*OTSP),
ii. to propose an improved technique of Genetic Algorithm (GA) with Simplified Swarm Optimization (SSO) algorithm's characteristic to prevent the loss of the genetic diversity in the population,
iii. to develop the propose technique in (2) for optimizing the *n*OTSP in term of finding the shortest path, and
iv. to evaluate the performance of the proposed technique with other GA variants in terms of shortest distance and population size.

1.4 Scope of the Study

This research focuses on single vehicle travels from a given starting point to an ending point in *n*OTSP with *n* number of cities. The performance of the proposed algorithm and the other GAs will be compared and analyzed in terms of the shortest tour and the influence of population size toward the solutions. In this research, the total number of cities *m* is set to be 50 as an experimental test case to represent the real cities. Thus, a set of 50 cities are represented as nodes in this study and all the nodes are generated randomly by computer. However, there is high possibility for starting and ending points are appeared to be closed to each other. Therefore, the manipulation of the starting and ending points will be conducted to ensure that they are far apart as what has been pictured in real-world scenario. In addition, four different data sets which represent the number of visited cities *n* are set to be 10, 20, 30 and 40 are employed. Moreover, each *n* is tested with 5 different population sizes *p*, that are 1000, 2000, 3000, 4000 and 5000. During each experiment, each *n* is executed 10 times on different *p*. Meanwhile, the performances of the proposed algorithm are compared with other GA variants, which are GA without crossover operator (GA-XX) and GA with one-point crossover (GA-1X). On the other hand, computational time and iteration are not taken into account in this research.

1.5 Thesis Outline

The remaining of the chapters are structured as follows.

Chapter 2 provides the fundamental theories regarding the optimization, TSP, GA, SSO and their applications. This is followed by reviews of the research made by past researchers and scholars in the similar field. In addition, this chapter lays a foundation for constructing the *n*OTSP and the proposed algorithm.

Then, Chapter 3 discusses the methodology used in this research. This details how the problem is constructed, how the proposed algorithm is developed, how the experiment is carried out systematically and how the results are recorded, calculated and analyzed.

Furthermore, Chapter 4 presents the analysis and results of this research. In this chapter, the proposed algorithm that has been developed in Chapter 3 is further validated for its efficiency and accuracy based on the recorded experimental results. The analysis and evaluations are carried out based on the computational results. Later, the reasons are justified.

Lastly, Chapter 5 concludes the research and findings as well as summarizing the contributions of the proposed algorithm are summarized followed by the recommendations of future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Many techniques have been proposed to optimize the Travelling Salesman Problem (TSP) or its variants in term of discovering the shortest route. Although many literatures covered a wide variety of the theories, this review only focuses on four dominant themes regarding the research topic. The four dominant themes are: the concept of optimization and its category, the definition of the TSP and *n*-Cities Open Loop Travelling Salesman Problem (*n*OTSP), the Genetic Algorithm (GA) as the base of the proposed technique and its application on similar problems, and the introduction of the Simplified Swarm Optimization (SSO) and its comparison strategy called solution update mechanism (SUM). Although many literatures have presented these themes through a variety of contexts, this study focuses on improved technique and its application on *n*OTSP. Thus, this chapter lays the foundation for the further development that is discussed in the next chapter.

2.2 The Concept of Optimization

Optimization happens everywhere and anytime, it ranges from simple problem to complex problem in daily routines. In addition to the industrial and scientific worlds, optimization also plays a significant role in controlling and maintaining the performance in minimizing and maximizing an objective function. For instance, business organizations have to maximize their profit and minimize the cost, engineering design has to maximize the performances of the designed product while of course minimizing the cost at the same time (Yang, 2008).

The root of "optimization" is "optimal" that carries the meaning of "best", "better" or "good enough" (Keeton *et al.*, 2007; Fletcher, 2013). In other words, the phrase "optimal solution" can be explained as the "best solution". Blum & Roli (2003) described optimization as concern the choice of a "best" configuration of a set of variables in order to achieve the goals. On the other hand, optimization can be defined as choosing the best solution among a given set of solutions (Khajehzadeh *et al.*, 2011). Therefore, the optimization theory and methods are needed to deal with the problems by selecting the best alternative based on the given objective function (Chong & Zak, 2013).

The area of optimization has received numerous attentions in recent years particularly in the field of computer science, including the development of user-friendly software, high performance processors as well as applied in solving various high complexity problems by providing efficient solution from all feasible solutions. For instance, in the Global Positioning System (GPS), optimization plays the role in guiding the driver to reach the destination by discovering and providing the best possible route. However, in general, the area of optimization can be divided into two main categories, which are continuous optimization and combinatorial optimization (Blum & Roli, 2003). Both types of optimization will be discussed in details in the next subsection.

2.2.1 Continuous Optimization

Continuous optimization is a branch of optimization in applied mathematics and it is the opposite of the discrete optimization, or combinatorial optimization. In continuous optimization, the variables are allowed to take on any values, which are usually real numbers (Gould, 2006). On the other hand, continuous optimization can be defined as finding the minimum or maximum value of a function of one or many real variable which subject to constraints. The constraints are usually in the form of equations or inequalities. This characteristic of continuous optimization shows it is different from combinatorial optimization, in which the variables in combinatorial problem may be binary, integer, or abstract objects that are drawn finitely from sets of many elements.

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VITA

The author was born in Jun 28 ,1989 in Bintulu, Sarawak. His early education started at Sekolah Rendah Jenis Kebangsaan Chung Hwa in 1995 for his primary school. In 2001 he continues his secondary school at Sekolah Menengah Kebangsaan Limbang. After completing his secondary school in 2005, he entered Sekolah Mengengah Kebangsaan Kubong for his pre-university in 2006 till 2008. Later, he pursued his first degree in Bachelor of Information Technology and Multimedia in Jun 2009 at University Tun Hussein Onn Malaysia. After he received his bachelor degree in 2012, he started his study in degree of Master in Information Technology at the University Tun Hussein Onn Malaysia in March 2013.