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MULTIPLE DRONES PATH OPTIMIZATION ALGORITHM FOR 3D SPACE PERFORMANCE USING CENTRALIZED VISUALIZATION PLATFORM

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Bachelor of Computer Science with Honors

(Computational Science)

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ABSTRACT

Path planning algorithm of Unmanned Aerial Vehicle (UAV) subject to find an optimal and collision free path in 3D space. With the popularization of UAV application, the drones are now can perform visualization by orderly flying within the airspace. However, UAVs face problem that low battery life when performing flying mission. Many algorithms have been done by researchers to solve the fast energy consumption problem. The existing methods aim for planning optimal path of drone flight. In this report, a variant of A, Theta* algorithm is proposed to find the optimal path within a grid-based environment. The reason of choosing this algorithm is that Theta* is fast and simple that able to find the shortest and realistic path. The proposed algorithm, with the inclusion of the triangle theorem, is utilized in this project to further boost performance of drones in trajectory planning. The result of this project conclude that proposed algorithm able to optimized the A* algorithm in term of total path travelled, maximum path travelled by single drone and number of turn. After testing with designed stimulator, results also prove that the efficiency of the proposed algorithm is higher under certain space occupancy.*

ABSTRAK

Algoritma perancangan laluan untuk Kenderaan Udara Tanpa Pemandu (UAV) bertujuan mencari laluan yang optimum dan bebas daripada perlanggaran dalam ruang tiga dimensi. Aplikasi UAV amat popular pada zaman ini. Dengan itu, UAV berkemampuan melaksanakan visualisasi sambil terbang dalam ruang udara tersebut. Walau bagaimanapun, UAV masih menghadapi masalah iaitu kekurangan hayat bateri apabila melaksanakan misi perterbangan. Banyak algoritma telah dijalankan oleh penyelidik untuk menyelesaikan masalah penggunaan tenaga yang cepat. Kaedah yang sedia ada bertujuan untuk merancang laluan optimum penerbangan drone. Dalam makalah ini, varian algoritma A *, iaitu Theta * dicadangkan untuk mencari laluan yang optimum bagi setiap drone dalam persekitaran berasaskan grid. Theta * pantas dan mudah yang dapat mencari laluan yang paling singkat dan realistik. Algoritma yang dicadangkan, termasuk teorem segitiga, telah digunakan dalam projek ini untuk meningkatkan prestasi drone dalam perancangan trajektori. Hasil daripada projek ini menyimpulkan bahawa algoritma yang dicadangkan dapat mengoptimumkan algoritma A * dari segi jumlah jalan yang dijalani, jalan maksimum yang dilalui oleh drone tunggal dan bilangan belokan. Selepas menguji dengan stimulator yang direka, hasil juga membuktikan bahawa kecekapan algoritma yang dicadangkan adalah lebih tinggi dalam penghunian ruang tertentu.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Unmanned Aerial Vehicle (UAV), also known as drone, is an aircraft without human pilot onboard but has capability of landing and vertical take-off. Usually drone is controlled remotely by embedded system on ground or it can fly autonomously with software-controlled flight plan. Over the past few years, drone technology is greatly developed by worldwide scientists and used in various scenarios such as remote sensing, aerial surveillance, exploration of oil, gas and mineral and disaster relief. One of a great achievement had been accomplished by Intel's drone team. It was a fleet of 300 lit-up drones performing choreographed maneuvers to spell out Wonder Woman's trademark "W" symbol (Weisberger, 2017).

The objective of UAV path planning problem is to arrive at the given point within a prespecified time. Meanwhile, maximizing the safety of UAVs. The path planning method of drones is slightly similar to method used by robot. The difference is UAV must maintain its velocity above a minimum velocity, which implies that the drone cannot follow a path with sharp turns or vertices (Jun & D'Andrea, 2003). Moreover, a simple 2D path planning algorithm is unable to deal with 3D environment. Although path planning in 3D dimension has great potential, but the difficulties increase exponentially with dynamic constraints.

Performing drone swarm in the midair as done by Intel's drone team is not an easy task. Consideration of constraints and requirements are important to produce desired result. After identifying them, relationship for each other is also needed to be clearly analyzed. In order to plan optimized path for drones through cluttered environment, a set of mathematic tools are needed to model constraints and store data. From the optimization theory point of view, finding a 3D complete path is NP-hard problem. Hence, there exist no common solutions (Yang et al., 2014).

Within this project, several of searching algorithms are studied to optimize and find a best way for multiple drones to travel. There are some constraints must be considered when drone fly from one dedicated point to another in outdoor environment. For example, in a same time, two drones cannot be at a same point while flying in the air. Unrestricted area may easily cause the drones out of their original path. Therefore, the airspace should be configured properly with the designed algorithm to ensure generated paths have no conflict.

1.2 Problem Statement

UAV has become one of increasing interest to many. The function of these unmanned aircraft is numerous, from military to commercial being, two areas of specific example. As consequence of this awareness to the benefit of such situation, there has been many research into the collision avoidance problem (DuToit et at., 2015). When there are multiple drones working in a same space, collisions or near misses become real issue. Path planner is one of the key elements of drone control module. In robotics community, research on drone path planning is actively studied. The main problem while compiling path planning of multiple drones is to find a collision-free path in 3D space. Unlike a car travels on road, drone flying path is difficult to control and maintain since they can travel any degree while in air. As a result, collision between one another and obstacle or near misses' issue are easily occurred. Path of drones configured with single centralized system must comply to optimized algorithm to avoid the issue.

1.3 Scope

Project scope is part of the project planning to determine boundary of the project. The project scope is important while developing because it is a guidance to lead developers work on correct path. In this project, the scopes are specified and described as shown below:

a) The target users for this system are people or organizations who wish to visualize their representative image or product in public airspace through drone swarm performance.
b) Drones visualization performs in limited 3D grid-based airspace with defined number of vertices that represent stopping points.
c) Space occupancy of drone in the 3D environment is between 15% - 50% to test the performance of algorithm.

1.4 Objective

The first objective of this project is identifying the requirements of drone performance for path optimization. Constraints such as background properties, drones position, minimum and maximum length interval of two stationary drones and flying speed are important to optimize drones' trajectory in time critical environment.

After the constraints and requirements are determined, the next objective is to design a path optimized algorithm for drones' space visualization. Each step of algorithm is clearly written to avoid error during path planning. Finally, the drones able to perform in the airspace by moving one node to another without collision using the designed algorithm.

The third objective is developing a prototype system based on the designed and developed algorithm. Each drone will move to desired coordination according to user input such as shape transformation or other formations. To verify the system functionality, several tests will be carried out such as using different drone swarm formations. At the end of each test, measuring position and altitude of drones when they stopped at destination respectively to see whether they are in the right place as expected. Purpose of several tests is to ensure the system is working under any circumstance.

1.5 Methodology

Methodology can be defined as the study or description of methods to conduct a research or develop a project. An appropriate methodology should be planned to ensure project completeness and get desired result. Methodology of this project is subdivided into several phases.

The first of everything will be define the problem. Objective of this phase is to identify and understand the problem regarding drone path planning in 3D space. The problems and the constraints involved are studied and listed in this report to ensure the designed algorithm could be cope with large scale of problem subsequently.

The next phase will be carried out is review on existing work. Many researchers had done their researches before and those can be used as comprehensive guide for synthesize existing knowledge. Strength and weakness of different approaches are compared and analyzed by exploring more relevant works.

In algorithm design phase, an optimal path finding algorithm is proposed and all constraints need to be identified. For example, velocity of drones while in air and ability of making turn are key factors of drone performance. Visualization of drone swarm performance can be perfectly done if taking consideration of those crucial factors while modeling the path.

In implementation phase, the designed algorithm which has ability to control multiple drones travel in the midair and perform drone visualization shall be implemented. Programming language that will be used is Python due to limitation of the drones. At the end of this phase, a complete and logical algorithm for drone trajectory planning is expected. The designed algorithm might have possibility to be changed or refined as goes further of this project.

After implementation, testing is the following phase to ensure the system is working well. During testing phase, some bugs definitely could be found such as time calculation or drones coordination problem. For example, the drone formation does not complete in time or collision occur while testing. Therefore, the coding part will be keep improving until the performance fulfils expected result. In addition, result obtained from designed system are analyzed to conclude whether the proposed algorithm able to optimize the trajectory planning.

The final phase is report writing. The development results and prototype performance are analyzed and documented. Strengths and weakness of the algorithm are identified during analysis. The purpose of writing report of project is act as reference that can be used for further improvement.

1.6 Significance of Project

Flying object in mid-air can easily dodge obstacles which are comparative rich on ground. Drones are often used for surveillance or shooting work by locating them at higher altitude to cover larger area. Besides, they are also used to perform attractive drones' visualization such as image showing or animation. In this project, the optimal algorithm that will be designed later could be apply on drone swarm visualization. The designed algorithm allows drones flying within a 3D environment using the lowest cost of path without collision. To accomplish such achievement, developing an algorithm that optimized by certain constraint is a key activity. The designed algorithm is used to optimize path planning of multiple drones and avoid collision among each other. In other words, it helps the drones to find their optimal path and reach said point. Advantage of optimized algorithm is improving overall drone's performance and efficiency. For example, an advanced drone algorithm called DroNet which is using a deep neural network in guiding the drone. This algorithm enables the drone to differentiate between moving and standing still objects (Zhang, 2018). Using these indications drone can independently navigate while avoiding crash.

1.7 Project Schedule

The project schedule for developing this project is shown in Gantt Chart (as attached in Appendix A).

1.8 Project Outline

This project consists of several chapters which are literature review, methodology, simulation, testing and conclusion.

The chapter of literature review is focusing on overview of research sources used in similar projects. Investigate and understand how other researcher solve the problem. Comparisons of the reviewed approaches are listed out to perform analysis. Algorithms and methods that decided to use are proposed in the end of the chapter.

The chapter methodology will report on the basic concept of the method used in our work. Analysis that has been conducted to generate useful information and data necessary for design phase is discussed. The preliminary concept of the approach selected will be deliberated.

Implementation is a crucial chapter to describe how the algorithm is applied on multiple drone path planning. The process of path planning must be carried out carefully by taking consideration of several key constraints such as path of length and computational time. Triangle theorem is applied as well to avoid collision between drones in the limited 3D environment.

The next chapter will be testing and debugging. This chapter presents the details of implementation of the project which consists of classifier and voting functions based on the design created. Testing and analysis of result based on different modules sizes will be discussed.

Finally, the last chapter concludes the work that has been done in this project. Analysis and suggestion for future work of the project will be discussed with the aim of improving the current accuracy and enhancing the designed algorithm for future purpose.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In this chapter, several existing researches regarding drone path planning algorithms done by others will be studies and reviewed. Based on that, various significant information and a better understanding on strength and weakness of each approach can be gained. A algorithm is considered optimal if it has low time computation, short path length and suitable for grid-based dimension. Comparison and discussion of algorithms will be made to propose a best solution for the problem.

2.2 Graph search algorithms

Graph search algorithms have been developed for computer science to find shortest path between two nodes within a connected graph. These algorithms were developed and designed for computer networks to establish routing protocols and were applied to path planning by decomposed the path into waypoint sequences. The optimization goal of these algorithms is minimizing distance covered by the vehicle. However, none of its performance or kinematic characteristic is perfectly optimized through the path. After environment is discretized, the algorithms treat each cell of the mesh as graph node and search the shortest path using “greedy” logic, which means define following steps by analyzing reduced number of cells and the path is obtained step-by-step. As a result, these algorithms only generate suboptimal solution but not real optimal path to reduce computational time. Due to the simplicity, these algorithms are suitable to deal with complex mission management system for multitask platform or vehicle.

2.2.1 Dijkstra algorithm

In 1959, Dijkstra discussed the problems aim to minimize cost of path within connected graphs. This searching algorithm computes shortest path with non-negativity edge path cost in a graph.

Dijkstra algorithm begins at a starting node and extends outward regularly within the graph until reaches all nodes. The reason is Dijkstra algorithm need to store the information and compute the minimum cost edge by summation. Next, the algorithm determines the costs between the starting node and goal node including all other vertices in the same graph. Hence, it has high success rate and robustness and it also may be useful in alternative decision making. However, due to large extending edges, it costs huge amount of time in computation.

The algorithm creates labels associated with various vertices (Tan et al., 2006). Cost from initial vertex to goal vertex is represented by the labels. There are two types of label: permanent and temporary label. In each stage, the reached vertices and known cost of that vertices to source vertex are given permanent labels whereas temporary labels are given to vertices that have not been reached.

2.2.2 A* algorithm

The A* algorithm has the potential to search a huge area of the map. It’s like Dijkstra’s algorithm that it can be applied to find a shortest path as well and breadth first search (BFS) that it can use a heuristic to guide itself. In the simple case, it is as fast as BFS. Since the worst-case for the breadth-first search is must consider all paths to all possible nodes result in time complexity is increasing depend on the nodes and edges number in the graph.

Van Tooren et al. (2007) adapted and implemented A* for multiple drones as a search over nodes of motion primitives that are short trajectory segments. Each of these motion primitive is chosen so that a flyable, smooth trajectory valid for the current state can be generated. Before the nodes are being chosen, each node which is maybe included in drone flight path will be rated by taking account of cost of path. At the end of it, this algorithm branches out a path with lowest estimated cost.

In computer science, something known as "heuristic" is used to find the estimated cost. It consists of two parts for each node, the known cost where it took to reach that node and estimated cost of reaching goal node from that initial node. Sum of these two parts become the final estimated cost.

According to Moses et al. (2008), the best-designed algorithm for general searching of optimal paths is A*. All the nodes are ranked by an estimate of the best route that goes through that node. The general formula is expressed as:

$$f(n) = g(n) + h(n) \tag{1}$$

where f(n) is score assigned to node n, the lower the f(n) value the higher the priority of n node to be selected, g(n) is the actual cheapest cost of travelling from initial node to n and h(n) is heuristic estimate of cost to the goal from n.

2.3 Sampling based algorithms

This method requires pre-known information of the workspace where the drones operate. Usually, it samples the environment as a set of nodes, or other forms, then map the environment or just search randomly to find an optimal path. There are two sub-categories of sampling based algorithms which are passive and active. Active means algorithm such as Rapidly-exploring Random Trees (RRT) can form a skeleton to the goal all by its own processing procedure. Passive is defined as algorithms like Probabilistic Roadmaps (PRM) that can generate a road net map from start node to the goal, but there exist a set of paths.

2.3.1 Rapidly-exploring Random Trees Algorithm

The Rapidly-exploring Random Trees (RRT) algorithm has been widely used to robotics fields as it's simple implementation and has the ability to solve the kinodynamic problem. Path planning algorithms using RRT to generate paths for multiple unmanned aerial vehicles (UAVs) in real time, by considering the kinematic constraints of the UAVs (Kothari, Postlethwaite, Gu, 2009). Same as the other algorithm, the objective of RRT algorithm is to find a path to travel from start point to goal point through configuration space.

In basic-RRT, a bunch random tree in high-dimension is keep growing until the goal node becomes a node of the random tree. Meanwhile, RRT searches paths that are formed and find the nearest node. The tree is grown by adding new edge at each iteration from one node to another. Figure 2.3.1 illustrates how "branching" method that used by RRT. Basically, this algorithm works with three main steps according to Tsai et al. (2015):

a) Generation of random nodes: Pick random nodes in 3D environment.
b) Expansion: Pick a random node and build connection between the node and nearest node in the random tree

c) Termination condition: Join the goal node to the random tree

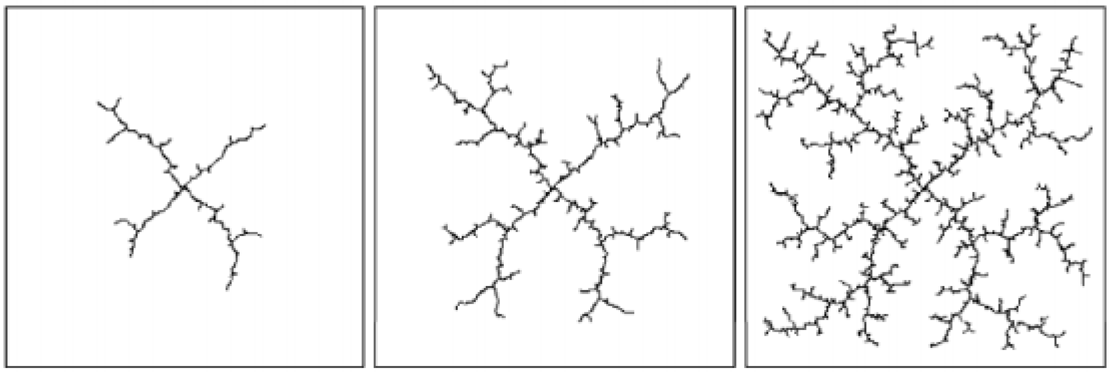

Figure 2.3.1: "Branching" expansion as result of RRT algorithm

Creating collision free path for multiple UAVs that are flying simultaneously is not easily can be done due to space constraints that one path imposes on the other. To ensure it work perfectly, each drone has own path planner to exchange information with other drones when they are in communication range to resolve conflict.

As in drone perspective, each of them starts expanding from own initial point. Random "branching" technique is used during the period. It can form more than one path by connecting to different "branches". However, the path form might not the shortest path and path looks might not realistic.