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Fundamental Analysis of Low Energy Path Routing for Delivery Quadcopters

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Abstract: The quadcopters are widely used for hobby use, video recording, etc. The home delivery service using quadcopters is one of hopeful applications of quadcopters. However, the flight time of quadcopters is limited due to the battery capacity, and the flight planning is very important for parcel delivery service to utilize the limited flight time effectively. In this paper, we propose low energy path routing method for delivery quadcopters. Proposed method is based on the nearest neighbor method, and we compared two types of costs functions of low energy path routing problem. In the experiment, we compared two types of proposed methods with optimal solution. Experimental results demonstrate the flight distance priority is effective low energy consumption in the given scenario.

Keywords — Quadcopters, traveling salesman problem (TSP), nearest neighbor method, energy consumption

1. Introduction

In recent years, the unmanned aerial vehicles (UAV) such as quadcopters are widely distributed for hobby use, video recording, etc. The home delivery service using quadcopters is well known as hopeful applications of quadcopters. However, the flight time of quadcopter is limited due to the battery capacity constraint. For example, the major quadcopters such as Parrot AR. Drone 2.0 [1], DJI Phantom 4 [2], etc. cannot fly more than one hour. This is a big constraint for the delivery quadcopters, and the effective flight planning is necessary.

In our preliminary experiment, energy consumption of quadcopters proportionally increases by the load (weight of total packages). This is an important feature because the energy consumption of quadcopters depends not only on flight distance, but also on package delivery order. This is a big difference between conventional traveling salesman problem (TSP) [3].

In this paper, we propose low energy path routing method for delivery quadcopters. Proposed method is based on the nearest neighbor method. We introduce two types of cost functions such as distance and total weight, and the obtained solutions are compared with the optimal results obtained by exhaustive search.

The rest of this paper is structured as follows: problem formulation of low energy path routing is described in Section 2. Proposed methods based on the nearest neighbor method are explained in Section 3. Experimental results are shown in Section 4. Finally, Section 5 concludes this paper.

2. Problem Formulation

The path routing problem is considered as one of traveling salesman problem (TSP) that can formulate as follows.

Let $C = \{c_0, c_1, c_2, \dots, c_m\}$ be the set of city. Especially, we call c_0 as delivery base, and the others are called destination. Then, delivery route is described as $\langle c_{\pi(0)}, c_{\pi(1)}, c_{\pi(2)}, \dots, c_{\pi(m)} \rangle$. Notice that the quadcopter departs at delivery base. Thus, $c_{\pi(0)} = c_0$.

Let $d(c_i, c_j)$ be the distance between c_i and c_j. We assume that the weight $w(p_i)$ is weight of package p_i, which is delivering package for c_i. We define $W_{\pi(i)}$ as total weight just after the quadcopter departed $c_{\pi(i)}$. Then $W_{\pi(i)}$ is described as follows.

$$W_{\pi(i)} = \begin{cases} \sum_{j=1}^{m} w(p_j) & (i = 0) \\ W_{\pi(i-1)} - w(p_{\pi(i)}) & (otherwise) \end{cases} \quad (1)$$

Then, total energy consumption to deliver the all package to corresponding destinations is calculated as follows:

$$E = \sum_{i=0}^{m-1} e\left(d\left(c_{\pi(i)}, c_{\pi(i+1)}\right), W_{\pi(i)}\right) + e\left(d\left(c_{\pi(m)}, c_{\pi(0)}\right), W_{\pi(m)}\right), \quad (2)$$

where $e(d, w)$ means the energy consumption to fly distance d with total weight w. Notice that the total energy consumption also includes the energy consumption to return to delivery base from last destination.

Then the low energy path routing problem for delivery quadcopter is described as follows: for given set of delivery destination and package, the problem outputs $\langle c_{\pi(0)}, c_{\pi(1)}, c_{\pi(2)}, \dots, c_{\pi(m)} \rangle$ to minimize total energy consumption given in Eq. (2).

3. Low Energy Path Routing Methods

In this section, we describe the path routing method based on nearest neighbor method. We assume that current city is $c'$and $cost(c_i, c_j)$ is cost function between c_i and c_j. The variable k means visiting order. Then proposed algorithm is described as follows:

1. $k = 0$. $c' = c_0$. All destinations are set to non-visit.
2. $\pi(k) = 0$. This means $\pi(0) = 0$.
3. Find c_i from non-visited destinations such that $cost(c', c_i)$ is minimal. The city c_i is set to visited, and $c' = c_i$. Additionally, $k = k + 1$. Then $\pi(k) = i$.
4. If $k = m + 1$, then output $\langle c_{\pi(0)}, \ldots, c_{\pi(m)} \rangle$. In otherwise, go to 3.

In this paper, we prepare two cost functions: flight distance and weight. DFS (distance-first search) is the method such as $cost(c_i, c_j) = d(c_i, c_j)$. WFS (weight-first search) is the method such as $cost(c_i, c_j) = -w(p_j)$.

4. Experimental Results

In this section, we evaluate the proposed path routing methods with two cost functions. We prepared 12 benchmarks such that the number of cities is 4, 6, 8, or 10. We prepare three benchmarks for each number of cities. In order to evaluate the method, we also searched the optimal solution for each benchmark by exhaustive search.

The distance $d(c_i, c_j)$ is randomly selected between 100 and 2000. The weight of package $w(p_i)$ is also randomly selected between 100 and 1000. In order to calculate total energy consumption, $e(d, w)$ is defined as follows:

$$e(d, w) = \big(K + (\alpha \cdot w)\big) \cdot d, \qquad (3)$$

where K and α are coefficients. In this experiment, we set as follows: $K = 10, \alpha = 0.01$.

Table 1 shows the experimental results for each benchmark. "DFS" and "WFS" mean relative error between the optimal result and the results obtained with each cost function. Table 2 summarizes the average for each benchmark with the same number of cities.

The experimental results show that the relative error tends to become larger with the larger benchmarks. Additionally, mean of the error shows that DFS is better than WFS in terms of energy consumption. These results are just one result of given specific conditions, and further experiment is necessary.

5. Conclusions and Future Work

In this paper, we proposed low energy path routing method for home delivery service using quadcopters. Proposed method is based on the nearest neighbor method, and two cost functions such as flight distance and total weight are prepared. Experimental results show that the routing method based on flight distance first search consumes lower energy than the method with weight first search.

This paper is a first paper to discuss about path routing problem of delivery quadcopters. We performed the experiments under the limited scenarios, and various experiments are necessary for further discussion. Especially, the effect of coefficients should be investigated. Additionally, the other scenarios such as installment delivery are hopeful options to minimize energy consumption.

Table 1. Relative error [%]

Sample No.	#City	DFS	WFS
1	4	0.0	79.0
2	4	0.3	3.0
3	4	8.0	0.6
4	6	16.0	140.0
5	6	31.0	4.0
6	6	16.0	46.0
7	8	32.0	116.0
8	8	7.0	64.0
9	8	0.0	172.0
10	10	27.0	112.0
11	10	8.0	140.0
12	10	20.0	118.0

Table 2. Average of error for each benchmark [%]

#City	DFS	WFS
4	2.8	28.0
6	21.0	63.0
8	13.0	117.0
10	18.0	123.0

References

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[3] M. R. Garey, D. S. Johnson, *Computers and Interactability – A Guide to the Theory of NP-Completeness*, W. H. Freeman & Co., 1979.