Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 48-9 (2015) 204–209

Area Allocation Algorithm for Multiple UAVs Area Coverage Based on Clustering and Graph Method

Sungjun Ann*, Youdan Kim, Jaemyung Ahn*****

**Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul, Republic of Korea, (e-mail: sungjun9037@snu.ac.kr)*
*** Department of Mechanical and Aerospace Engineering, Seoul National University, Seoul, Republic of Korea, (e-mail: ydkim@snu.ac.kr)*
****Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology, Daejon, Republic of Korea, (e-mail: jaemyung.ahn@kaist.ac.kr)*

Abstract: Coverage problem has variety of applications such as area allocation for surveillance and reconnaissance of the unmanned aerial vehicles (UAVs), which can be converted into multiple traveling salesmen problem. To formulate the area coverage problem for UAV mission assignment, obstacles in the given area should be considered. In this study, area allocation algorithm is proposed for area coverage problem. Area allocation algorithm consists of area partitioning and area revision. Area partitioning produces collision free subareas for the UAV, and area revision reassigns nearly uniform coverage area to each UAV. The proposed algorithm is based on clustering method and graph method. To demonstrate the performance of the proposed algorithm, numerical simulation is performed.

© 2015, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.

Keywords: Area Coverage, Multiple UAVs, Clustering Coverage, Multiple Traveling Salesmen Problem, Graph Cut, Area Partitioning

1. INTRODUCTION

Coverage problem is a map based path planning problem which aims to visit the whole given area. Robot-assisted missions such as surveillance, reconnaissance, exploration, and inspection can be considered as the coverage problem. Recently, many researchers have studied the coverage problem to efficiently operate multi-robot system. Multi-robot coverage problem can be formulated as a multiple traveling salesman problem(MTSP), which aims to visit all the given cities by multiple salesmen along minimized paths. Bektas (2006) stated that MTSP could be applied to reconnaissance mission or planetary exploration.

The MTSP is a non-deterministic polynomial-time hard(NP-hard)problem, and requires a lot of computation time to obtain optimal solution. Therefore, researches have focused on obtaining sub-optimal solution to reduce the computational time. Somhom *et al*. (1999) suggested a heuristic MTSP algorithm based on artificial neural network (NN). Williams and Burdick (2006) proposed a sub-optimal solution based on clustering approaches for boundary inspection. Xu and Stentz (2011) obtained sub-optimal solution using k-means clustering algorithm for edge coverage problem. Ernest and Cohen (2012) provided a solution methodology based on fuzzy clustering Genetic Algorithm (GA) for a polygonal area visiting problem, which is a Dubins MTSP.

Few studies addressed the MTSP problem with the path constraint. Faigl (2010) provided an approximate solution for a multiple watchman route problem for a selection of nodes (cities). Areas were decomposed into a set of Delaunay triangles, and nodes were determined by visibility test. Somhom *et al.* (1999) applied the MTSP algorithm for the suitably selected nodes. Fazli et al. (2013) obtained solution for the repeated area coverage problem based on the clustering method. Reduced visibility graph and reduced constrained Delaunay triangulation were used to avoid obstacles, and clustering algorithm was used for task allocation. Then, a chained Lin-Kernighan algorithm was applied to solve the TSP on the clusters.

In this study, area allocation algorithm based on clustering method and graph method is proposed to deal with area coverage problem including obstacles. The proposed algorithm provides collision free subareas without performing visibility test. The computational time of the proposed method is fast even though it does not reduce nodes. The feature of the proposed algorithm is that it assigns uniform task for UAVs despite heuristic approach.

This paper is organized as follows. In Sec. 2.1, preliminaries and problem definition are introduced. The proposed collision free partitioning algorithm with revision is described in Sec. 2.2 and Sec 2.3. Simulation results are provided in Sec. 3. Finally, concluding remarks are given in Sec. 4.

2. AREA ALLOCATION FOR MULTIPLE UAVs

2.1 Preliminaries and Problem definition

2405-8963 © 2015, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2015.08.084

A reconnaissance missions for multiple UAVs can be formulated as an MTSP. In this problem, each UAV is considered as a salesman, and the given area should be decomposed into appropriate multiple nodes. The whole area is represented as a non-overlapped set S_{all} consisting of unit cells. The cells are possible candidates for nodes except for some cells denoted by S_{obs}, which represent the obstacles or a restricted area. Using these definitions, a node set S can be defined as follows.

$$S = S_{all} - S_{obs} \tag{1}$$

To solve the MTSP, the number of depots, the path type, and the optimization criterion for MTSP should be determined in advance (Wang (2013); Faigl. (2010)). In this study, it is assumed that the number of depots and the number of UAVs are the same. It is also assumed that the path type is 'open,' which indicates that UAV does not have to go back to the starting depot. The criterion for the MTSP is MinMax, which is the minimization of the longest path. There exist two approaches (Bektas. (2006)) to solve the MTSP; One is to find an exact (optimal) solution, and the other is to find a sub-optimal solution by using heuristic approach. Because the MTSP is an NP-hard problem, heuristic algorithm is widely used to assure the computational efficiency. In this study, the MTSP is first converted into multiple TSPs by dividing the entire area into sub-areas, where the number of the sub-areas is same as the number of UAVs. Then, the TSP algorithm using heuristic approach is applied to each of subareas to find the route.

The proposed algorithm consists of two parts. First, collision-free subareas are generated. By doing this, it can be assured that collision between UAVs as well as collision between UAVs and the obstacles do not take place during the mission. In the second part, the subareas are updated to find the partitioning that minimizes the longest UAV path. By doing this, each UAV can perform nearly equivalent amounts of mission.

2.2 Area Partitioning for Multiple UAVs

Basic idea of area partitioning is to utilize a clustering algorithm. In the area allocation problem of multiple UAVs, obstacles in the given area should be considered. In this study, $\alpha\beta$ swap algorithm (Boykov *et al.* (2001)), which was originally proposed for image restoration or image segmentation, is adopted to deal with this problem. The main purpose of the algorithm is to find a label assigned to each pixels so that every pixel is assigned to a label in a label set. For the proper assignment, appropriate energy function should be designed with respect to the labelling l. The energy function $E(l)$ consisting of data part E_{data} and smooth part E_{smooth} can be described as follows

$$E(l) = E_{data}(l) + E_{smooth}(l) \tag{2}$$

The data part describes how well the pixel is matched to the label, and the smooth part represents how smooth the labels are distributed. In this way, labelling with minimum energy function provides a proper assignment. The minimization is accomplished by using virtual links consisting of t-link (i.e., link between label and pixel) and n-link (i.e., link between pixel and pixel), along with the Maxflow algorithm (Boykov *et al.* (2004)) that finds min-cuts within the links. Here, the cut t-link is found when the label is assigned to the pixel.

In this study, the cell corresponds to the pixel and the UAV corresponds to the label. The label set L is defined by multiple UAVs as follows

$$L = \{UAV_1,\ UAV_2, \cdots,\ UAV_n\} \tag{3}$$

where n is the number of the UAVs. The data part is related to overall area partitioning. On the other hand, the smooth part is related to smoothing of the area partitioning. The data part and smooth part of energy function are defined as follows.

$$E_{data}(l) = \sum_{s\in S} D_s(l_s),\ \ E_{smooth}(l) = \sum_{\{s,r\}\in \mathrm{N}} V(l_s, l_r) \tag{4}$$

Where a function D determines a relation between the UAV $l_s \in L$ and the cell $s \in S$, a function V determines a relation between the pair of neighbor cells $\{s,r\}$, and a set N is the set of interacting pair of cells. The links are constructed by D and V as follow.

$$S_{UAV_n} = \{s \mid s \in S \cap l_s{=}UAV_n\},\ S_{UAV_{n,m}} = S_{UAV_n} \cup S_{UAV_m} \tag{5}$$

$$t_s^{UAV_n} = D_s(UAV_n) + \sum_{\substack{r\in \mathrm{N}_s \\ r\notin S_{UAV_{n,m}}}} V_s(UAV_n, l_r),\ \ s \in S_{UAV_{n,m}} \tag{6}$$

$$e_{\{s,r\}} = V_s(UAV_n, UAV_m),\ s,r \in S_{UAV_{n,m}},\ \{s,r\} \in N \tag{7}$$

where S_{UAV_n} is set of cells s assigned to UAV_n, $t_s^{UAV_n}$ is the t-link between the cell s and the UAV_n, and $e_{\{s,r\}}$ is the n-link between the cell s and the cell r. Note that each cell should have one cut in the t-link. If a cut occurs in the n-link, then neighbouring cells $\{s,r\}$ are assigned to different UAVs.

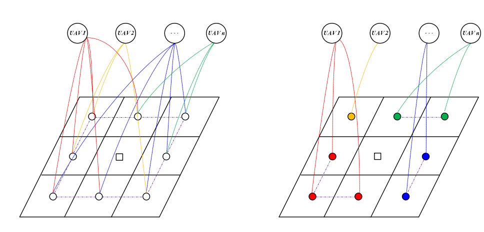

Fig. 1. (a) Before (b) After applying the $\alpha\beta$ swap algorithm

Figure 1 shows the $\alpha\beta$ swap algorithm graphically. A square-shaped cell is a member of S_{obs}, and a circular shaped cell is a member of S. The initial links are shown in Figure 1(a). The t-links are shown as dotted line and the n-links are shown as dash-dot line. Figure 1(b) obtained by the $\alpha\beta$ swap

Download English Version:

https://daneshyari.com/en/article/713110

Download Persian Version:

https://daneshyari.com/article/713110

Daneshyari.com