Chapter 1

Introduction

1.1 Title Page

Optimized Waypoints selection for UAV maximum area coverage

Mark Bastourous

Laboratoire d'Electronique,Informatique et Image
Universite De Bourgogne

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1.2 INTRODUCTION

The final objective of this thesis research is to design a global optimization scheme allowing a cameras network to be self organized or to plan single camera trajectory, according to fixed priority and constraints, in order to ensure a full coverage of a given scene. The main problem of UAVs is the autonomy of fly, because of the battery run-time. This short time action restrained the possibility to use a set of UAVs and the work cooperation for a long time surveillance if there is no much UAVs available at the moment. One smarter possibility is to create a monitoring path with several UAVs which alternately automatically relays when the battery is low. During the navigation of the UAV's path, it is possible to get the image of the area to survey and build the mosaic of the area. This paper will focus on finding the best waypoints for the UAV to pass through, to reduce the computation usually done in the path planning and coverage process. In order to find a good path to cover most of the area the essential point is to propose the best waypoints.

ensures complete coverage of the terrain while minimizing path repetition

indoor gps denied slam methods were used to localize and navigate the UAV using the visual

Chapter 2

Background

The shit about 1- Area coverage 2- global path planning

Boustrophedon cell decomposition based coverage method

not Boustrophedon area coverage from right to left and from left to right in alternate lines.

veer the uav from the desired path

2.1 Introduction

The merit of this thesis in the coverage path planning context is splitting the process of the coverage problem into finding the proper pose and orientation of camera positions that maintain area coverage and the path planning technique . So that the first part can be used as a solution by itself with positioning Cameras in the obtained points.

The second merit is minimizing overlapping

A two-level approach to collision-free navigation, using artificial potential fields on the lower layer (local solution) and GA TSP as global layer solution

then point-to-point motion planning problem, where the vehicle task is to navigate from a pre-specified initial point in the workspace to a pre-specified destination goal point

Chapter 3

Optimized Waypoints Selection

3.1 Related Work

Finding the waypoints to have the best coverage of the area is close to the problem of positioning cameras or sensors to cover an area efficiently. Sensor positioning problem has been investigated since a few decades, mainly for video surveillance [?]. Without any additional constraint, this problem is NP-Hard as stated in [?, ?, ?, ?, ?] for the Watchman Route Problem (which is very similar to the optimal positioning waypoint for UAV path). Two non-optimal solutions have been proposed. The first one is based on Art Gallery Problem (AGP) [?, ?] and the second one is based on the Wireless Sensors Networks [?, ?, ?, ?] trying to find the best position to design an efficient network which can collect data with any kind of sensors.

However, the solution proposed to the problem addressed the coverage problem but linked with additional and specific constraints, which are out of our scope.

One of the algorithm used is the Particle Swarm Optimization (PSO) as detailed in [?, ?]. Zhou *et al.* [?], some experimental results are provided and one solution running in real time is proposed. However, the scene used in these experiments is rather small and many cameras are employed to fully cover it. On the other hand, [?] uses a cost function but the cost function is not only focused on the position for surveillance and coverage, but also handling resolution and lighting, which affect the final solution by not covering the under illuminated areas. Reddy *et al.* [?] also introduced the concept of acceptable response, allowing non-optimal/sub-optimal solutions. If the coverage score is higher than a given threshold, the solution is accepted and not locked by the research of an optimal solution.

Our paper is inspired by [?, ?], extending the method for UAV waypoints positioning and path planning in more complex environments (basic room, big room, non-square shape).

3.2 Coverage

3.2.1 Context of experiment

The main purpose of our work is to estimate the position of n camera waypoints for surveying a given area in order to maximize the visual coverage. Each camera provides a top view of the area similar to UAV views. The coverage area of each camera is defined by the projection of the visual field onto the ground. This way, the mosaic composed by the captured images should be very close to a complete top view of the area. In order to find the best coverage many experiments have been done to compare PSO and also GA. PSO is easier to implement and runs faster but GA is more flexible and generic thanks to the many tunable parameters. The following subsections will give an overview our method, which is based on GA, and provide a comparison between PSO and GA that demonstrates the overall advantage of the latter on the former.

3.2.2 Cost function

Since the goal is to maximize the visual coverage of the camera network, a cost function has been chosen to quantify it, as follows:

$$\sum_{i=1}^{n} = \frac{cover(i)}{size(grid)}_{1 \leq i \leq n}, \tag{3.1}$$

where n is the number of waypoints; $grid$ represents the discretization of the ground plane (floor); $cover($ ... $)$ is a function which computes the area on the ground which is covered by at least one camera ; $size(...)$ is the dimension of the full area which must be $covered(grid)$.

Camera projection model is not explicitly taken into account, but the ground-projected visual field instead, as described in Fig.3.1.

3.2.3 Genetic algorithm

Motivated by Darwin's theory of evolution and the concept of survival of the fittest, GAs use processes analogous to genetic recombination and mutation to promote the evolution of a population that best satisfies a predefined goal [12]. Such kind of algorithms require the definition of a genetic representation of the problem and of a cost function used to evaluate the solution. The candidate solution is represented by a data structure named chromosome, defined by Eq.(3.2) with x, y and z the cartesian coordinates and θ the rotation of the camera with respect to the optical axis: only two possible angles are allowed, $0°$ or $90°$ (portrait or landscape). To pass from an iteration (or generation) to the other a few steps are necessary `figures/interp-eps-converted-to.pdf`

Figure 3.1: Projection of the camera on the ground.

(see Fig.3.2).

$$A = \begin{bmatrix} X_i \\ Y_i \\ Z_i \\ \theta_i \end{bmatrix}_{1 \leq i \leq n} \tag{3.2}$$

In our experiments, we empirically fixed the number of chromosomes to be 90, the mutation rate to be 0.001 and the crossover rate to be 0.919.

3.2.4 Context of experimentation

In order to compare the two algorithms and evaluate their performances, we tested them on different scenarios depicted in Fig.3.3, with areas of different sizes and shapes, where:

- z is the height of the camera between (within the range $[1/z; z]$).
- Figure 3.3(a) is an area of size 120×80 (named Room).
- Figure 3.3(c) is an area of size 240×160 (named Big room)
- Figure 3.3(b) is an area of size 120×80 (named Room U)
- Figure 3.3(d) is an area of size 120×80 (named Room L)
- Figure 3.3(e) is an area of size 240×80 (named Big room L)

The design of experiments in Table 3.1 has been set up to identify the most efficient algorithm for the positioning of a set of waypoints with the maximum of coverage.

z=1		GA		PSO	
		GT	NW	GT	NW
Room	120x80	16	20	16	20
	240x160	64	70	64	70
Room U	120x80	12	20	12	20
z=2		GA		PSO	
Room	120x80	4	10	4	10
	240x160	16	20	16	20
Room L	120x80	3	10	3	10
	240x160	15	20	15	20

Table 3.1: Design of experiment for compare the efficiency of PSO and GA in different condition. (GT is Ground Truth and NW is Number of Waypoints).

The Ground Truth (GT) is the minimum number of waypoints required to fully cover a given area. The size of the area has been selected so that the GT can be easily estimated.

NW is the maximum number of waypoints (or camera views) used for the experiments. At each experiment a solution is computed for a number of waypoints from 1 to NW. In order to compare the different algorithms in similar conditions, only 10000 calls of the cost function is allowed for each set of waypoints.

3.2.5 Analysis of the result

After performing the design of experiments (see Table 3.1) it appears that GA and PSO algorithms are close in performance. In some cases GA is much more efficient (see in Fig.3.4) particularly in the case where the search space is large (big room and big number of cameras) as example in Fig.3.4). Instead PSO is more effective to optimize small areas (see in Fig. 3.5). This efficiency can be explained by the small variation of the solution introduced by the PSO.

However, this small variation is not enough to find an optimized solution in a big search space which happen when a lot of cameras are required or when the local minima is deeper. Although the variety of solutions introduced by the GA allow to escape from local minima, it can affect negatively the accuracy of the solution, which may require a further optimization step to refine.

Following the comparison of the 2 algorithms, the GA seems more suited to find UAV waypoints especially if it navigates in a large room or outdoor scene. Furthermore, the comparative study demonstrated that the GA is less dependent on the shape of the covered area.

figures/GAfinal.jpg

Figure 3.2: GA explanation, from one generation to the other.

figures/Room1.png

(a)

figures/room3.png

(b)

figures/room2.png

(c)

figures/room4.png

(d)

figures/room5.png

(e)

Figure 3.3: Scenarios used for the experiments: (a), (b), (c) are with z=1 and (d), (e) with

figures/GAPSObigRoomz1ters.png

Figure 3.4: Comparison of eight solution given by GA, eight solution given by PSO algorithms with a Z equal to 1, in the big room 240x160 and ground truth equal to 64.

figures/GAPSORoomLz2bis.png

Figure 3.5: Comparison of eight solution given by GA, eight solution given by PSO algorithms with a Z between [1/2; 2], in the room with L shape 120x80 and ground truth equal to 15.

Chapter 4

Optimized Path Planning

In this paper, a hybrid Artificial Potential FieldGenetic Algorithm approach is developed and implemented for mobile robot path planning in dynamic environments. The hybrid approach first uses Grid Method where the mobile robot environment is represented by orderly numbered grids, each of which represents a location in the environment. Then, it applies Genetic Algorithm (GA), a global planner, to find an optimal path according to the current environment. The GA proposed here uses an evolutionary population initialization and genetic operators, which make the evolutionary process converge very efficiently. Finally, a new Artificial Potential Field method, a local planner, is applied to follow the path obtained by GA from one intermediate node to next intermediate node avoiding the obstacles. Experimental results clearly illustrate that the proposed hybrid approach works well on large scale dynamic environments http://download.springer.com/static/pdf/746/chp

some operations research methods, such as traveling salesman problem (TSP), chinese postman problem and rural postman problem can be considered. In this case TSP was taken into account.

autonomous navigation of an aerial robot based on the combination of evolutionary algorithms and artificial potential fields.

Normally path planning optimization techniques does not stritctly put passing by the defined waypoint a hard constrain for their solutions. In this case hard constrains of passing by the waypoins are taken into account.

4.1 Problem Formulation

4.2 Global planning

In the previous section, the method to obtain the list of waypoints has been detailed. Verified by simulation that passing through all of these waypoints the desired area coverage will be attained. The list of waypoints needs now to be sorted to compute an efficient path with smoother shape and shorter traveling distance.

There are several ways to formulate this problem. In this paper, two methods have been implemented and compared.

Shortest Path Problem

Normally finding a shortest path between two points in configuration space is mature enough. Dijkstra , A* and many other methods are extensively studied in the field of In our case we assume the waypoints as multi goals. So the planning in this method will simply finding at every waypoint the shortest euclidean distance from the other available non-traversed waypoints. Based on that a ranked waypoints list will be generated. This will not guarantee a globally shortest distance but will only choose the shortest distance every time a waypoint is visited.

Traveling Sales Man Problem

The sorted path can be formulated as traveling sales man optimization problem (TSP). Every node which is a point in space is represented as a city and the euclidean distances between the cities are calculated and used as cost function. The path is organized based on the minimum distance traversing over all the cities (or waypoints). To find an optimized solution GA is here again used.

The privilege of TSP problem formulation and solving it using GA over the other shortest path algorithms like Dijkstra, is that it provides global complete solution traversing all the waypoints not finding a path from a starting node to a goal node. The GA approach is more clarified and discussed by Trevor *et al.* [**?**].

4.2.1 Local Path Planning

After succeding in getting the main waypoints sorted in a way to gurantee shortest path distance, now comes the issue of generating the mid points that the robot should traverse to generate the trajectory.

As an example, quad-rotors kinematics gives hovering capabilities to these platforms. This feature permits to relax turning constraints on the path (which represents a crucial problem for fixed-wing vehicles).

Linear piecewise

The previous process will provide a list of sorted waypoints co-ordinates. These waypoints are dealt as graph nodes, that need to be connected to have a path, so the problem is formulated as a linear piecewise function. Hereby the used linear piecewise function used in Eq.(4.1).

$$f(x) = \begin{cases} 0 & \text{if} \quad x \leq a \\ \frac{x-a}{b-a} & \text{if} \quad a \leq x \leq b \\ \frac{c-x}{c-b} & \text{if} \quad b \leq x \leq c \\ 1 & \text{if} \quad c \leq x \end{cases}, \tag{4.1}$$

where the line segment between points a and b will be the line between every waypoint and the consecutive one. The third point is c and depending on the number of waypoints variables will be added in the formula.

`figures/DijkstraPath2.png`

`figures/Path_planned_G.png`

Figure 4.1: Path before and after being sorted

The distance covered by path that is planned by GA is 513 meters which is shorter by the factor of 1.8 compared to the distance covered by Dijsktra multi goal approach which is 963 meters.

Spline interpolation

find the shortest smooth path through consecutive waypoints.

It is advisable not to have sudden change in the first derivative or the slope of the function (linear between the points).

length of the interpolant = there is a way to calculate it check

When the interpolation is assumed to be piecewise linear, this is easy. However, if the curve is to be a spline, perhaps interpolated as a function of chordal arc length between the points, this gets a bit more difficult. A nice trick is to formulate the problem in terms of differential equations that describe the path along the curve. Then the interpolation can be done using an ODE solver.

Artificial Potential Field

Chapter 5

Experiments and Results

The computer hardware specs used to generate this experiments: blabla bla

5.1 ROS

it was bound with v-rep

5.2 Simulation

5.2.1 VREP

Room

Many rooms were built in Vrep .

UAV simulation

Camera mounted

specs of the camera and changing it.

UAV model Twist message mathematical can be found in lecture 7 graph_slam of visual navigation for flying robots .. slide 50

5.2.2 Gazebo

5.3 Real World

5.3.1 UAV

Unmanned ariel vehicles hisotry of it and categorization like VTOL and so on .

The Quadrotor used to do this experiments is an offshelf commercially found drone from the French company parrot which is AR.drone 2.0 . further information about the drone can be found in ....

Odometry Pose Estimation: The Pose Estimator is explained in the following article and Masters Thesis [23], [22]. To correct the drift that the Odometry Pose Estimator module has, absolute measures provided by visual features are used.

tum$_a rdronepackagewasutilizedtogenrateworkofvisualslamusingthefrontalcameraandthisasexplainedinthep$

(usage of the down camera) is used to get the

without learning the environment or mapping it precedently, this method is used.

Chapter 6

conclusion

6.1

6.2 Future Work

Appendix A

The first appendix

If you need to add any appendix, do it here... Etc.

Appendix B

Glossary

UAV Unmanned Aerial Vehicle