Probabilistic Approach to Planning Collision Free Path of UAV

Krzysztof Skrzypczyk, Adam Gałuszka, Marcin Pacholczyk, and Krzysztof Daniec

Abstract. In this paper an approach to planning collision free path based on probabilistic search is presented. The aim of this study is to design an algorithm for off-line planning a set of way-points which make the collision free route of an UAV. The planning process is based on the map that contains information about altitude of the terrain over which the UAV is intended to perform its mission. The probabilistic method of making the representative model of the terrain was applied in order to reduce a complexity of planning the collision free path. The functioning and efficiency of the approach proposed was illustrated with some exemplary simulations.

Keywords: probabilistic planning, UAV, surface models.

1 Introduction

The design and construction of Unmanned Aerial Vehicles (UAV) have become one of the most important and strategic branches of the contemporary Robotics. It is caused by a plenty of possible applications of this kind of automatons. Efficient and robust UAV are desired in many branches of industry. For instance in the military sector the UAV is a perfect tool for performing patrolling and reconnoitring missions. On the other hand in the civil sector of industry, unmanned vehicles are very useful for inspecting of large constructions as well as for monitoring, for instance, the traffic intensity in large cities. Of course there are many more potential and desired applications. Those aforementioned ones, are only examples which aim is to highlight an importance of this area of robotic research. Regarding the

Krzysztof Skrzypczyk · Adam Gałuszka · Marcin Pacholczyk · Krzysztof Daniec
Silesian University of Technology, Institute of Automatic Control,
Akademicka 16, 44-101 Gliwice, Poland
e-mail: {Krzysztof.Skrzypczyk,Adam.Galuszka}@polsl.pl,
{Marcin.Pacholczyk,Krzysztof.Daniec}@polsl.pl

A. Nawrat et al. (Eds.): Advanced Technologies for Intelligent Systems, SCI 440, pp. 59–68.
springerlink.com

construction of the UAV there are two main conceptions of the design. First one (relatively the simplest in realisation) is a remotely controlled vehicle. In this approach flying vehicle is controlled remotely by human operator. Using vision feedback (a camera mounted on board of the vehicle) the operator is able to move the flying object over the place or the region of interest and inspect it or make a photographic documentation. The second conception is the autonomous aerial vehicle. Such device is the most desired one, but simultaneously also the most difficult in designing and constructing. In this approach, the vehicle is intended to perform autonomously the mission assigned by the operator. It is easy to imagine how hard the problem of constructing such system is. During the process of the design, there are many serious and difficult problems to solve. It is enough to mention the collision free path planning, the vehicle stabilising in changing whether conditions, determining the aerial position and orientation and many others. Due to the a large number of possible applications and benefits related to them, intensive researches have been done in this area. [1, 13, 12, 15, 16, 18, 20]. This paper addresses the first of pointed out issues - the problem of determining the collision free path. Intended application of the developed UAV control system is performing autonomously the patrolling mission over an unstructured terrain. The goal of the planner is determining the set of way points that make the route the vehicle is intended to follow. There are many methods and algorithms of planning collision free paths, derived in a straight-line from mobile robotics [3, 4, 5, 6, 7, 8, 9, 13, 14, 17, 23]. In this work the probabilistic approach [2, 10, 11, 21] to solving the planning problem was selected and applied. The main reason of this choice was the demand of meeting main assumption which was the simplicity of the planning method as well as the minimalism of the representation required for the planning. Since the planning problem in the 3D space is relatively hard to solve in terms of complexity and costs of computations, the two-level approach to planning the three dimensional path was proposed. Together with the probabilistic method of building the model of the world representation such approach allows generating the collision free path with a small computational cost. The planning process is based on the topological map that contains information about the height of the terrain over which the vehicle is intended to perform its patrol mission. The work of the method is illustrated with an exemplary scenario that was modelled and simulated using MATLAB environment.

2 Overview of the System

In this section a brief overview of the navigation and control system is presented, in order to clearly address the framework in which presented problem is solved. Figure 1 shows general diagram of the navigation and control system of the UAV. It is created on the base of a typical, known from mobile robotics hierarchical, hybrid

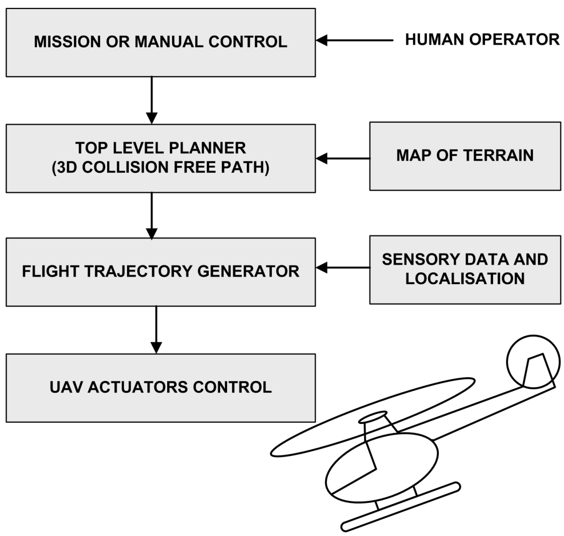

Fig. 1 The conceptual diagram of the UAV control system with the planner module being the point of the work presented

architecture. At the top level of the system, there is a module called *planner* which is the point of this study. The human operator assigns mission by specifying the places (points) the vehicle is intended to fly over. The role of the planner is to generate the set of way-points that determine the collision free path. The planner module is also provided with data about topology of the terrain. Using this data the model which is used further in the planning process is created. The next module is responsible for generating the collision free trajectory which enables the flight between the way-points.

The navigation module has to be also provided with information about the position and orientation in space. Determining the coordinates, and orientation is performed by the localisation subsystem. The plan created by the planner does not take into account the dynamics of the space inside of which the vehicle operates. Therefore the navigation system has to be also provided with data about existence of objects that can appear in the surrounding of the vehicle. This information is collected by the sensory system. The bottom level of this architecture is the motion control system which is to execute the trajectory generated by the navigation system. As it was mentioned before the core of this article is just the design and simulation evaluation of the algorithm dedicated to work with the planner module. The process of the design is presented and described in the rest part of this paper.

3 Problem Formulation

3.1 Assumptions

The planning system presented here is designed for the UAV which purpose is patrolling the frontiers areas. However it is created to satisfy a number of conditions and assumptions. They make some limitations for possible application and the framework in which the system work properly. So it is important to clearly point them out and discus. The following are the main assumptions that were followed during the design process:

- The patrol mission is performed on the given, priory stated height H_o.
- There is a map that provides information about height of the terrain points.
- The manoeuvre of avoiding obstacles is preferred to the flying over them

The assumptions pointed out, are the main limitations of the planning method presented. However they are realistic and justified and they do not limit the system to only simulation studies, and make the method applicable in real systems.

3.2 Problem Statement

Let us first define the mission to be performed by the UAV. The mission in fact is the collection of locations defined by human operator the vehicle is intended to fly over as well as the altitude H_0 of the flight. Let us denote the mission as the set:

$$M = \{m_1, m_2, ..., m_P\}, \quad m_i = (x_i, y_i),\ i = 1, 2, ..., P \tag{1}$$

The goal of the planner module is to calculate in the 3D space a set of points that lay between the locations defined by operator. Therefore for each pair of points:

$$(m_i, m_{i+1}),\ i = 1, 2, ..., P-1 \tag{2}$$

the module is intended to find a set of way points that determine the collision free path defined in 3D space:

$$S_i = \{s_{i,1}, s_{i,2}, ..., s_{i,Q}\},\ s_{i,k} = \left(x_{i,k}, y_{i,k}, z_{i,k}\right),\ i = 1, 2, ..., P-1 \tag{3}$$

As it was mentioned before the overall process of calculating the path in 3D space is split on two stages. First one is determination the path in 2D space and second - extension the original path on the 3D space. All further discussion will be made, without the loss of generality, for a single pair of points defined in (2), and denoted hereafter as: m_1, m_2. Of course all the process can be repeated for any pair of the points.

4 Map of the Terrain

The process of planning the collision free path is based on the assumption that the system is provided with the map that contains data about height of each point of the terrain. In this work the map was modelled using simulated sculpture of the earth's surface. It was made using the mixture of Gaussian. Figure 2 shows an exemplary model of the terrain. The next step is to apply a regular grid of the given resolution and put it on the model. If the single cell of the grid has dimensions equal $c_x \times c_y$ and resolution of the grid is $N \times M$ the model will cover the area of $Nc_y \times Mc_x$. With each cell there is related the altitude attribute that is determined as a maximal height in the region covered by given cell. This results in attributing the height parameter to each cell of the grid. Let us define the model of the workspace as the matrix:

$$H = \{h_{i,j}\} \quad i = 1,2,...,N,\ j = 1,2,...,M,\ h_{i,j} \in \Re \tag{4}$$

Such model is the base for the planning algorithm.

5 Planning

5.1 Probabilistic Approach

Since the search space in 3D models is large that implies hard computations have to be performed in order to find the solution. The probabilistic approach allows to simplify the problem. Instead of searching through entire space a number of representative elements are selected. For instance if the map has a resolution 100x100 in the process of searching the solution requires 10000 elements to be processed.

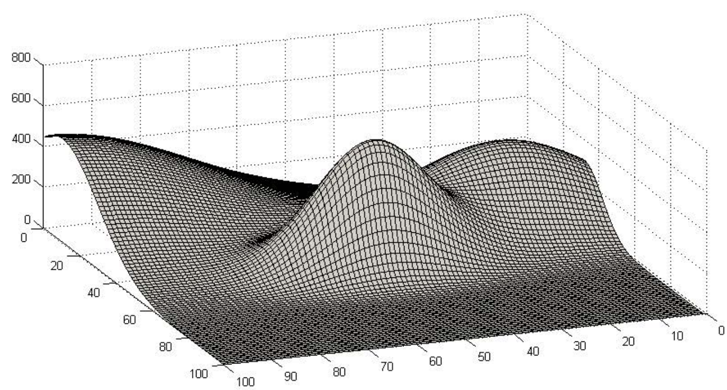

Fig. 2 Simulated model of the terrain

Therefore the number Z of representative elements from the model (4) is randomly selected. The planner searches the optimal solution using the reduced space. Let us denote the randomly selected set of representative samples of the original model as:

$$R = \{r_1, r_2, ..., r_Z\} \tag{5}$$

where

$$r_i = \{k, l\},\ k = \langle 1, N\rangle \text{ and } l = \langle 1, M\rangle \tag{6}$$

In (6) the elements k, l are integer values selected in a random way from the given range. An exemplary containing 25 elements, random realisation of the subspace is presented in fig. 3. Using representative elements contained in (5) the process of search the collision free path is performed. If the size of the (5) is not large enough or the distribution of points does not allow to find admissible solution, the process of selecting the representative subspace is repeated or the size of the set (5) is increased.

5.2 Graph Model

The next stage of the process of finding the solution is creating the model that will be a base for the planning process. Here in this study the graph representation of the random subspace is proposed. Hence the model has a form of weighted graph defined as:

$$W = (V, E) \tag{7}$$

where

$$V = \{v_1, ..., v_{Z+2}\},\ E = \{v_i, v_j\},\ w_{i,j} \neq \infty,\ \ i, j = 1, 2, ..., Z+2 \tag{8}$$

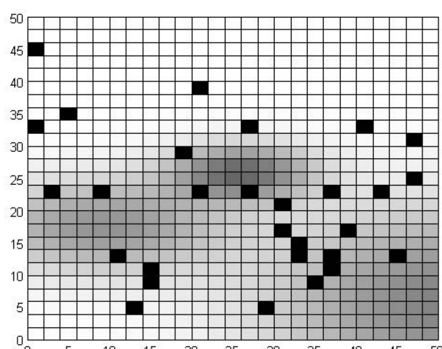

Fig. 3 An exemplary subspace generated in a random way

In (8) v_1 and v_{Z+2} are equal to m_1 and m_2 correspondingly which are defined in (2). This set defines the vertices of the graph (7). Second part of the graph model is the set of edges E. It defines mutual, spatial relations between elements defined by V as well as costs of transitions between any given pair of vertices. Calculation of costs is a crucial part of the model creation. All the process of planning is based on the graph representation so the quality of the model is critical for this process. In this the cost between two elements of the set V is calculated as:

$$w_{i,j} = \left\| v_i - v_j \right\| (1 + S_{i,j}) \tag{9}$$

where $\left\| v_i - v_j \right\|$ denotes euclidean distance between ith and jth vertex, and:

$$S_{i,j} = \sum_{k=1}^{K} L_k \Big|_{v_i}^{v_j} \tag{10}$$

is a sum of altitudes read from the map (4) along the line that connects vertex ith with vertex jth. This mapping is done according the following rule:

$$L_k = \begin{cases} 0 & \text{for altitude} < H_0 \\ H_{m,n} & \text{for altitude} >= H_0 \end{cases} \tag{11}$$

As a result of determining costs of transitions between all pairs of vertices the cost matrix is created. It is denoted as:

$$D = \left\{ S_{i,j} \right\} \; i,j = 1,2,...,Z+2 \tag{12}$$

5.3 Solution

For the representation given by (12) searching the path of minimal cost is performed. There are many effective algorithms for minimal path search [4] but in this study the Dijkstra's algorithm was chosen. Since the graph defined by (12) is the complete one, always exists the path connecting vertices v_1 and v_{Z+2}. As a result of the graph search the path that connects those vertices is found:

$$P^* = \{p_1, ..., p_P\}, \; p_1 = v_1, \; p_P = v_{Z+2}, \; 2 \leq P \leq Z+2 \tag{13}$$

each element of the set (13) is a point in a 2D space. Next stage consists of transforming this solution into 3D space. This process is done by attributing each point of the (13) with appropriate altitude. This is done in the following way: For each pair p_k, p_l of points from the set (13) it is checked if for any point p_i that lays on the line between p_k, p_l the height determined by (4) is lower than H_0. If yes, the point is attributed with the coordinate $z_i = H_0 + \Delta H$ and this point is added to the solution. As a result of this iterative procedure the final solution defined in 3D space is determined:

$$P_F^* = \{p_{F1}, p_{F2}, ..., p_{FR}\},\ P \leq R \tag{14}$$

where each element p_{Fi} $i = 1, 2, ..., R$ defines a point in 3D space that has coordinates (x_i, y_i, z_i).

6 Simulations

In order to prove the efficiency of the presented method a number of simulation experiments has been performed. Here one relevant experiment is presented as an illustration of the functioning of the method. The map of the terrain that contains information about height was simulated using Gaussian mixtures. The modelled terrain has an altitude from the range 0 to 800 [m]. The map has a resolution 100 $\times$ 100. The grid of a resolution 25 $\times$ 25 was applied in order to create model of representation. The assumed altitude of the UAV flight was 150 [m]. The initial and the target point of the flight were set to (2,2) and (20,5) correspondingly. The size of the representative, randomly selected space was set to 25. Figure 4 presents results of the planning. This is and exemplary random realisation of the planning process, increasing the number of trials the path can be improved. Also increasing the size of the representative subspace the solution can tend to the optimal one. But due to the fact that the aim of the planner is only to generate way points of the flight trajectory in many cases the solution is feasible and can be applied to effective controlling the UAV.

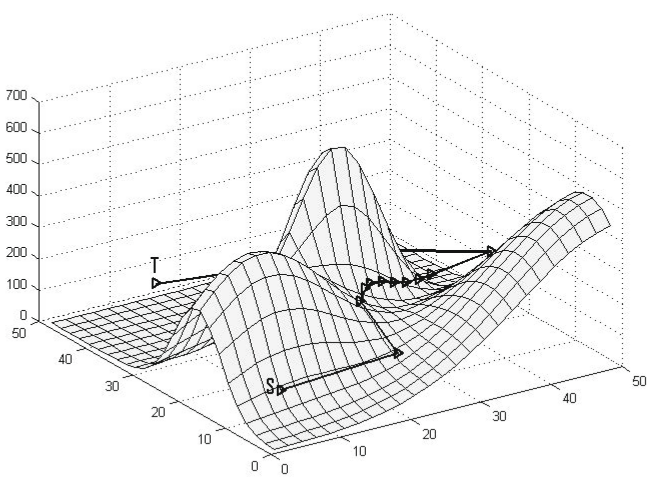

Fig. 4 An exemplary solution of the path planning process in 3D space, obtained obtained using the proposed method

7 Conclusions

In this paper an probabilistic approach to the problem of collision free path planning in 3D space was presented. The target application of the discussed method is determination of the way points of the flight of the UAV. Presented approach allows to find feasible path in 3D space simultaneously reducing the computations. Thanks to the simplification that consists in splitting the process on two stages the method is both effective and simple (in terms of computation costs). The simplicity was the one of the most important assumptions taken for the design of the UAV control system and the presented method satisfy it. Since the method is not deterministic it generates different solutions. After a number of simulations it was checked that all the generated solutions are also feasible ones and they are satisfactory for the overall UAV control system.

References

1. Adolf, F.M., Hirschmuller, H.: Meshing and Simplification of High Resolution Urban Surface Data for UAV Path Planning. Journal of Intelligent and Robotic Systems 61, 169–180 (2011)
2. Barraquand, J., Kavraki, L., Latombe, J.C., Motwani, R., Li, T.Y., Raghavan, P.: A random sampling scheme for path planning. International Journal of Robotics Research 16, 759–774 (1997)
3. Barraquand, J., Langlois, B., Latombe, J.C.: Numerical Potential-Field Techniques for Robot Path Planning. IEEE Transactions on Systems Man and Cybernetics 22, 224–241 (1992)
4. Deo, N.: Graph Theory with Applications to Engineering and Computer Science. Prentice Hall Series in Automatic Computation (1974)
5. Fujimura, K., Samet, H.: A Hierarchical Strategy for Path Planning Among Moving Obstacles. IEEE Transactions on Robotics and Automation 5, 61–69 (1989)
6. Ge, S.S., Cui, Y.J.: New Potential Functions for Mobile Robot Path Planning. IEEE Transactions on Robotics and Automation 16, 615–620 (2000)
7. Hsu, D., Latombe, J.C., Motwani, R.: Path Planning in Expansive configuration spaces. International Journal of Computational Geometry and Applications 9, 495–512 (1999)
8. Hwang, Y.K., Ahuja, N.: A Potential-Field Approach to Path Planning. IEEE Transactions on Robotics and Automation 8, 23–32 (1992)
9. Kambhampati, S., Davis, L.S.: Multiresolution Path Planning for Mobile Robots. IEEE Journal of Robotics and Automation 2, 135–145 (1986)
10. Kant, K., Zucker, S.W.: Toward Efficient Trajectory Planning - the Path-Velocity Decomposition. International Journal of Robotics Research 5, 72–89 (1986)
11. Kavraki, L.E., Kolountzakis, M.N., Latombe, J.C.: Analysis of Probabilistic Roadmaps for Path Planning. IEEE Transactions on Robotics and Automation 14, 166–171 (1998)
12. Kavraki, L.E., Svestka, P., Latombe, J.C., Overmars, M.H.: Probabilistic Roadmaps for Path Planning in High-Dimensional Configuration spaces. IEEE Transactions on Robotics and Automation 12, 566–580 (1996)
13. LaValle, S.M.: Planning Algorithms. Cambridge University Press (2006)
14. Lumelsky, V.J., Mukhopadhyay, S., Sun, K.: Dynamic Path Planning in Sensor-Based Terrain Acquisition. IEEE Transactions on Robotics and Automation 6, 462–472 (1990)

15. Lumelsky, V.J., Stepanov, A.A.: Dynamic Path Planning For a Mobile Automaton With Limited Information on The Environment. IEEE Transactions on Automatic Control 31, 1058–1063 (1986)
16. Lumelsky, V.J., Stepanov, A.A.: Path-Planning Strategies For a Point Mobile Automaton Moving Amidst Unknown Obstacles of Arbitrary Shape. Algorithmica 2, 403–430 (1987)
17. Nakamura, Y., Mukherjee, R.: Nonholonomic Path Planning of Space Robots Via a Bidirectional Approach. IEEE Transactions on Robotics and Automation 7, 500–514 (1991)
18. Nikolos, I.K., Valavanis, K.P., Tsourveloudis, N.C., Kostaras, A.N.: Evolutionary Algorithm Based Offline/Online Path Planner for Uav Navigation. IEEE Transactions on Systems Man and Cybernetics Part B-Cybernetics 33, 898–912 (2003)
19. Paik, D.S., Beaulieu, C.F., Jeffrey, R.B., Rubin, G.D., Napel, S.: Automated Flight Path Planning for Virtual Endoscopy. Medical Physics 25, 629–637 (1998)
20. Pehlivanoglu, Y.V., Baysal, O., Hacioglu, A.: Path Planning for Autonomous Uav Via Vibrational Genetic Algorithm. Aircraft Engineering and Aerospace Technology 79, 352–359 (2007)
21. Thrun, S., Burgard, W., Fox, D.: Probabilistic Robotics. MIT Press (2005)
22. Tisdale, J., Kim, Z., Hedrick, J.K.: Autonomous UAV Path Planning and Estimation An Online Path Planning Framework for Cooperative Search and Localization. IEEE Robotics and Automation Magazine 16, 35–42 (2009)
23. Zhu, D., Latombe, J.C.: New Heuristic Algorithms for Efficient Hierarchical Path Planning. IEEE Transactions on Robotics and Automation 7, 9–26 (1991)