

CZECH TECHNICAL UNIVERSITY IN PRAGUE
FAKULTY OF ELECTRICAL ENGINEERING
DEPARTMENT OF CYBERNETICS



BACHELOR THESIS

Název práce

Autor: Matěj Račinský

Thesis supervisor: Dr. Martin Saska

In Prague, 2015

Název práce: Název bakalářské práce

Autor: Matěj Račinský

Katedra (ústav): Katedra kybernetiky

Vedoucí bakalářské práce: Dr. Martin Saska

e-mail vedoucího: saska@labe.felk.cvut.cz

Abstrakt V předložené práci studujeme... Uvede se abstrakt v rozsahu 80 až 200 slov. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut sit amet sem. Mauris nec turpis ac sem mollis pretium. Suspendisse neque massa, suscipit id, dictum in, porta at, quam. Nunc suscipit, pede vel elementum pretium, nisl urna sodales velit, sit amet auctor elit quam id tellus. Nullam sollicitudin.

Klíčová slova: klíčová slova (3 až 5)

Title: Název bakalářské práce v angličtině

Author: Matěj Račinský

Department: Department of Cybernetics

Supervisor: Dr. Martin Saska

Supervisor's e-mail address: saska@labe.felk.cvut.cz

Abstract In the present work we study ... Uvede se anglický abstrakt v rozsahu 80 až 200 slov. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut sit amet sem. Mauris nec turpis ac sem mollis pretium. Suspendisse neque massa, suscipit id, dictum in, porta at, quam. Nunc suscipit, pede vel elementum pretium, nisl urna sodales velit, sit amet auctor elit quam id tellus. Nullam sollicitudin. Donec hendrerit. Aliquam ac nibh. Vivamus mi. Sed felis. Proin pretium elit in neque. Pellentesque at turpis. Maecenas convallis. Vestibulum id lectus.

Keywords: klíčová slova (3 až 5) v angličtině

Prohlašuji, že jsem svou bakalářskou práci napsal(a) samostatně a výhradně s použitím citovaných pramenů. Souhlasím se zapůjčováním práce a jejím zveřejňováním.

V Praze dne December 30, 2015

Jméno Příjmení + podpis

CONTENTS

Abstrakt	ii
Zadání práce	iii
1 Algorithm	v
2 Grouping of goals for guiding path	vii
3 Paths narrowing	ix
4 Implementation	xi
4.1 External libraries	xi
4.2 Code structure	xi

ALGORITHM

Basis of whole algorithm is here in pseudocode

Configuration variable is instance of Configuration class, which holds all configuration variables, including selected map. Map holds all Areas of Interest (AoI) and obstacles. All obstacles and AoIs are represented now as rectangles.

Even if we want to find as short path to AoI as possible, path too near to obstacles is not convenient for realization, because UAVs do not use car like motion model used in this simulation, so they can not exactly follow found trajectories. So in real environment, it is convenient for the swarm to have path planned with safe distance from obstacles. Because of that fact, we need to increase size of obstacles, which is done in line 2 in function amplifyObstacles.

Line 3 represents discretization of map to graph. Discretization divides map to squares with size set in configuration and each square is represented by node. In this graph, there are 4 types of nodes: Free, Obstacle, UAV and Goal. If part of square of whole square is covered by obstacle, corresponding node has type Obstacle. If part of square or whole square is covered by AoI, corresponding node has type Goal. If square contains UAV, corresponding node has type UAV and rest of squares have corresponding nodes with type Free.

Edges in this graph are only between nodes of neighboring squares, so each node has maximally 8 edges. Obstacle nodes do not have any edges.

After converting map to nodes, optional grouping of goals for guiding path can be turned on. I will cover the grouping in chapter 2.

Algorithm 1.1 Basis of whole algorithm

```
1: map := configuration.getMap();
2: map := amplifyObstacles(map);
3: nodes := mapToNodes(map);
4: paths := createGuidingPaths(nodes);
5: rrtPath := rrtPath(paths, map, nodes);
6: lastState := getBestFitness(rrtPath, map);
7: path := getPath(lastState);
8: path = straightenCrossingTrajectories(path);
9: path := optimizePathByDubins(path, map);
10: savePathToJson(path);
```

Line 4 calculates the guiding paths for rrt path algorithm using the A* algorithm. Algorithm has modified cost function and in addition to cost function of A* algorithm, cost of current node is added during the calculation. Nodes neighboring with obstacles has bigger cost than nodes which do not have obstacles as neighbors. Thanks to this modification, guiding path avoids obstacles and has bigger distance to obstacles.

On line 5 the rrt path algorithm takes place. This function returns structure with tree with root at starting position of UAVs and with array containing leaves of this tree, where all UAVs are in Areas of Interest.

On line 6 the leaf, where UAVs have best coverage of AoI is chosen. Quality of coverage is determined by cost function, which will be mentioned later.

On line 7 the path is built from last state.

On line 8 is optional preparation before optimization using Dubins maneuvers. In the preparation, all crossings of paths of individual UAVs are straightened, so UAVs do not cross other UAVs trajectories during whole path. During implementation of this method were complications, which are covered in chapter, and thus the row was removed from the algorithm. 3

On line 9 is optimization by Dubins maneuvers. Optimizations is covered in chapter.

Last line is only persisting of path to file for usage of path by different program.

todo: možná
sem odkaz na
kapitolu

todo: možná
sem odkaz na
kapitolu

GROUPING OF GOALS FOR GUIDING PATH

During this processing of map (method `MapProcessor::getEndNodes` in codebase) all AoIs are grouped to one big AoI, which is the smallest rectangle covering all AoIs.

If this modification is turned on, instead of one goal for every AoI (node in middle of AoI rectangle is considered as goal node), only one goal is used for all AoIs. This prevents swarm to split and whole swarm has only one guiding path. The main reason to have one big swarm instead of more smaller swarms is that smaller swarms (or individual UAVs in case of same count of AoI and UAVs) is relative localization, which can be used better when having only one swarm.

Below are images of maps with goals and obstacles. Goals have green color and obstacles have grey color.

This approach has advantage, when individual AoIs are near to global goal of whole group, as seen in 2.2.

Disadvantage of this method is, when individual AoIs have big distance from each other than can be covered by UAVs, this approach totally fails, because RRT-Path, which is much faster than RRT, has goal very distant from AoIs, as can be seen in 2.1.

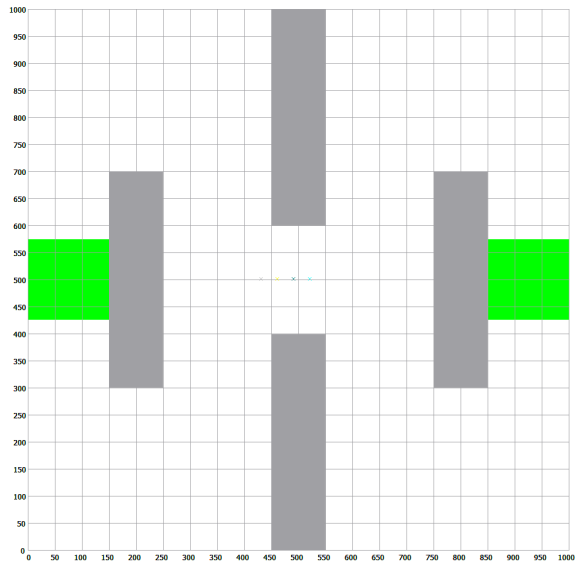


Figure 2.1: Map with goals unsuitable for grouping

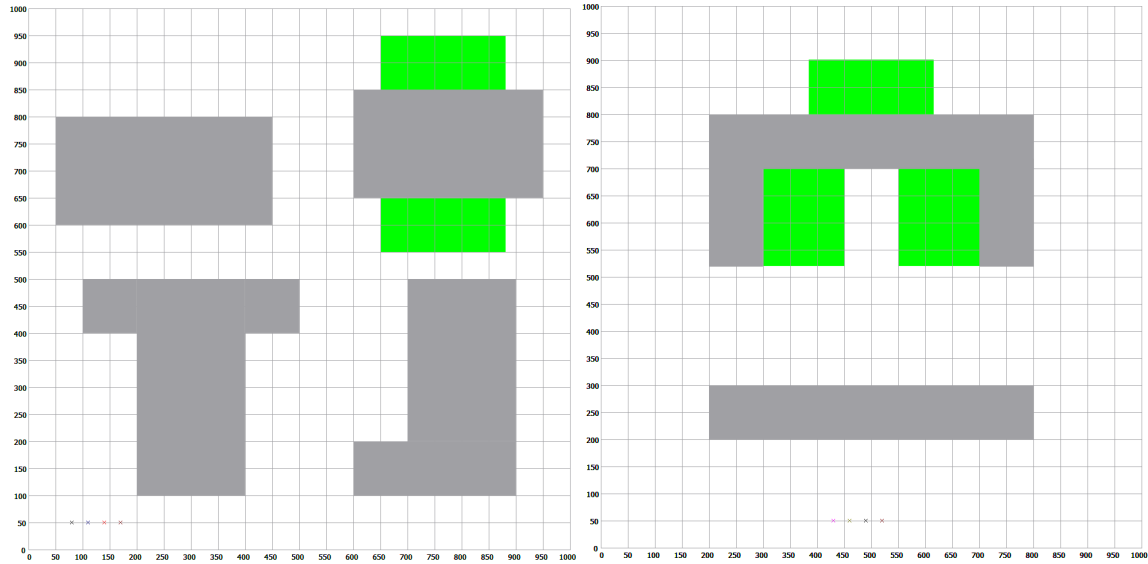


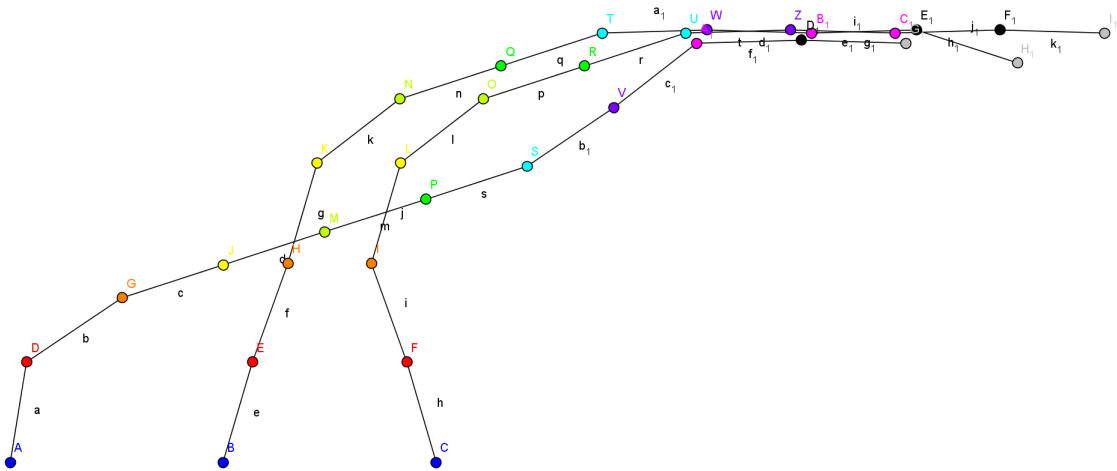
Figure 2.2: Maps with goals suitable for grouping

PATHS NARROWING

RRT-Path algorithm checks crossing paths between neighboring states, so between n -th state and $n+1$ -th state no trajectories are crossing each other. But between states trajectories are still crossing. In this image 3.1 is shown path found by RRT-Path. Every color marks one state in RRT-Path. As we can see, check in algorithm prevents from crossing path between neighboring states, but crossing of paths in different times can not be easily prevented. We can see in image, that paths cross between points J (yellow), M (light green) and H (orange), K (yellow), so there is no easy approach to prevent path collisions between $n-2$ -th state and n -th state. Optimization by Dubins maneuvers shortens trajectory of UAVs, so UAVs could be in these trajectories in different time, so there could be collisions after optimization. Another complication occurs, when time difference between two states is too low, then uavs could collide, because in reality UAV can not follow path precisely, but only with some errors.

I tried to straighten crossing trajectories, but all attempts failed. Straightening was done by switching parts of crossing paths from the earliest crossing state to end. But then paths had different lengths, which was unsuitable for path planning for swarm. This can be done by adding “waiting” points, points in different state but with same position in different time. But then is really hard to straighten longer path with many crossings (this path is really short, paths in other maps are much longer and more complicated). For motion model with inertia is also really hard to deal with waiting states, which complicates following of straightened trajectories. Due to all complications mentioned above, this part was removed from algorithm. But it is possible to add it, when better approach will be found.

Figure 3.1: Crossing paths



IMPLEMENTATION

This part will cover implementation of algorithm, which was used for simulations. Whole code-base can be found at this [github repository](#).

4.1 External libraries

In implementation are used some external libraries. Every used library is mentioned here. Boost libraries is used for smart pointers, libraries for Dubins maneuvers are from Master Thesis by Petr Váňa[1]. Generating of JSON from C++ object is done via Json Spirit library. Another external library is V-Collide from The University of North Carolina at Chapel Hill.

Because V-Collide sources were written in 1997 and because I used C++11 compiler to compile my source codes, I had to rewrite part of this library for compatibility and to make public API easier to use. Modifications can be seen in this [github repository](#).

Last use external library is QT, which was used to create platform independent GUI.

4.2 Code structure

Here is shown brief UML scheme demonstrating dependency diagram of codebase. To keep diagram simple, only services are displayed, other classes were left out. Diagram was generated using software StarUML

Core class holds core of whole Application and has all other classes as dependencies, as is shown in image 4.1.

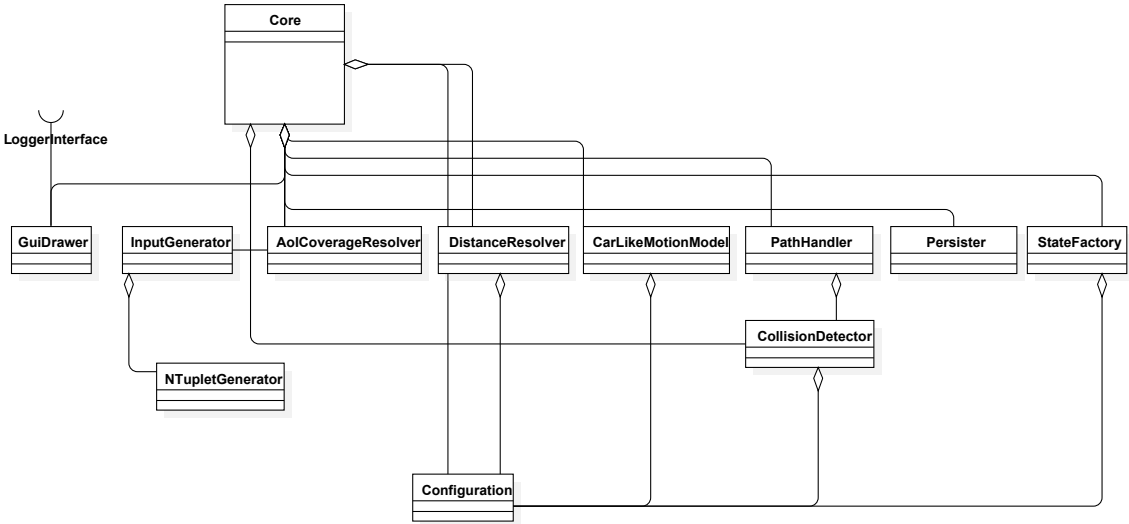
State factory creates State classes according to Factory pattern. State class represents state in RRT-Path algorithm. State has coordinates and rotations for all UAVs.

Persister persists found path to JSON using Json Spirit library.

PathHandler serves as utils class for manipulations with path (vector of State classes).

CarLikeMotionModel holds motion model algorithm.

Figure 4.1: Dependency diagram



BIBLIOGRAPHY

- [1] Petr Váňa, *Path Planning for Non-holonomic Vehicle in Surveillance Missions* [online]. [cit. 2015-12-29]. URL: <https://dspace.cvut.cz/bitstream/handle/10467/61814/F3-DP-2015-Vana-Petr-thesis.pdf>

