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A Path Planning Algorithm for an AUV Guided with Homotopy Classes

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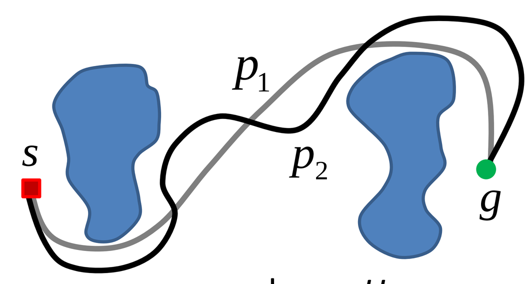
Abstract

We propose a method that uses topological information to guide path planning in any 2D workspace. Our method builds a topological environment based on the workspace to compute homotopy classes, which topologically describe how paths go through the obstacles in the workspace. Then, the homotopy classes are sorted according to an heuristic estimation of their lower bound. Only those with smaller lower bound are used to guide a planner based on the Rapidly-exploring Random Tree (RRT), called Homotopic RRT (HRRT), to compute the path in the workspace. Simulated and real results with an Autonomous Underwater Vehicle (AUV) are presented showing the feasibility of the proposal. Comparison with well-known path planning algorithms has also been included.

1 Introduction

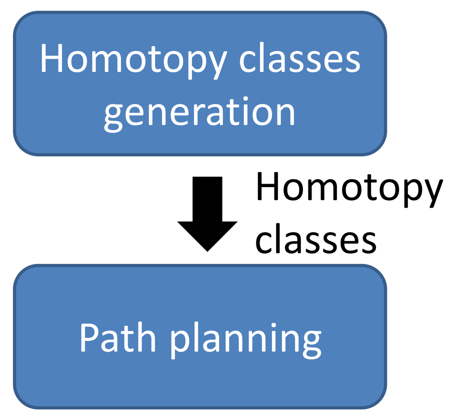
•**Guide topologically a path planning algorithm using homotopy classes**

•Two paths belong to the same homotopy class H if one can be deformed into the other without encroaching obstacles.



p_1 and $p_2 \in H$

•Two steps process

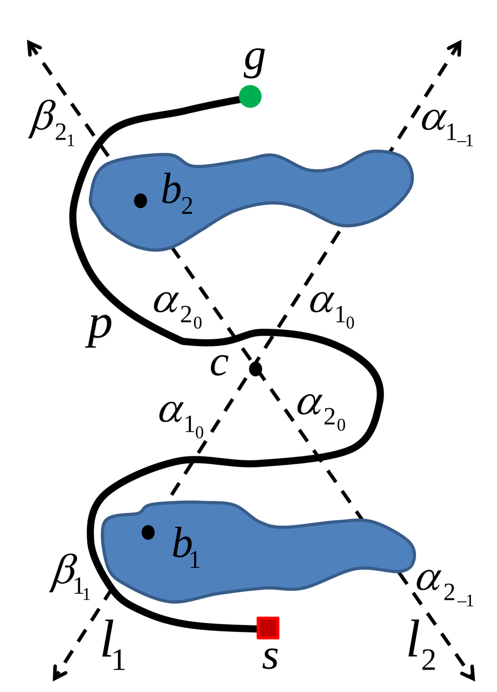


•Advantages
 •Explore the space confined in a homotopy class
 •Generate good solutions very fast if the homotopy classes with the lower cost solutions are known
 •Homotopy classes allow to reach the goal by avoiding the obstacles in different manners

2 Generation of the Homotopy Classes

•Construction of a topological environment to compute homotopy classes that can be followed in any 2D workspace

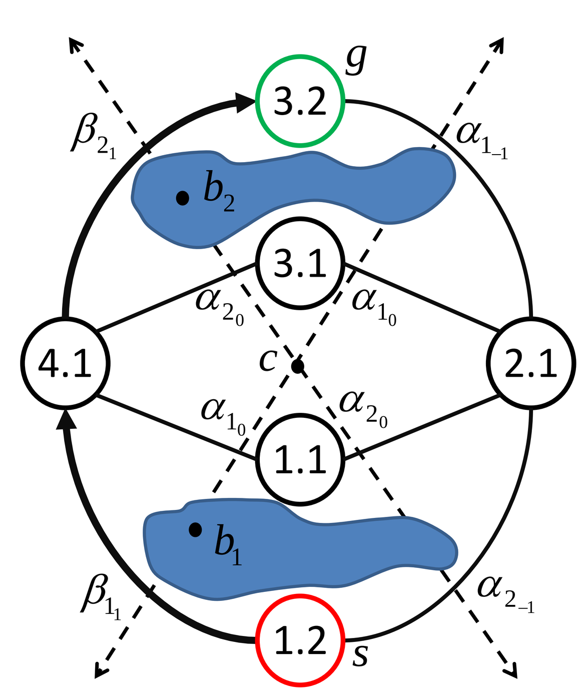
1 Reference frame (F)



$p = \beta_{1_1}\alpha_{1_0}\alpha_{2_0}\alpha_{1_0}\alpha_{2_0}\beta_{2_1}$

•Establish the **topological relationships between obstacles**
•Any path is defined by the sequence of the segments traversed

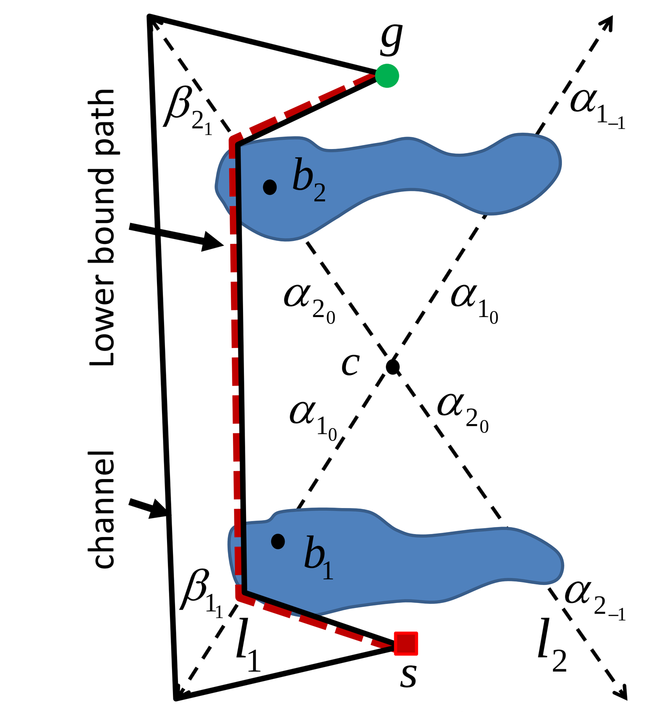
2 Topological graph (G)



$p = \beta_{1_1}\beta_{2_1}$

•Systematic generation of the homotopy classes **in their canonical form** with a modified BFS algorithm
•**Restriction criteria** to avoid self-intersections/duplicate

3 Lower bound



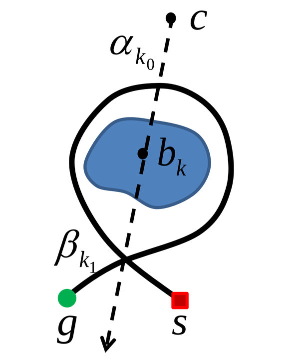
$p = \beta_{1_1}\beta_{2_1}$

•**Quantitative measure** of the homotopy classes before computing their path
•Modified version of the Funnel Algorithm

• **Simple wrap**

$\alpha_{k_s}\cdots\chi_{k_t}\cdots\alpha_{k_s}$

$\beta_{k_s}\cdots\chi_{k_t}\cdots\beta_{k_s}$

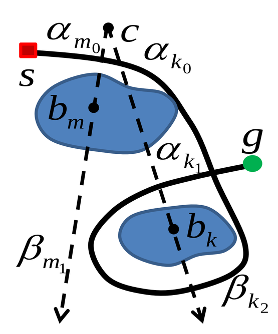


• **Wrap**

$\chi_{k_s}\cdots\chi_{k_t}\cdots\chi_{k_u}$

– with $s, t, u \geq 0$ and $s < t < u$

– with $s, t, u \leq 0$ and $s < t > u$



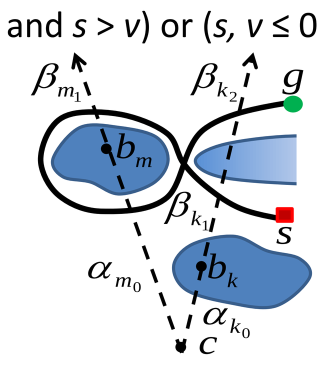
• **Self-crossing**

$\chi_{k_s}\cdots\beta_{m_t}\cdots\alpha_{m_u}\cdots\chi_{k_v}$

– ($s, v \geq 0$ and $s < v$) or ($s, v \leq 0$ and $s > v$)

• Or the reversed substring with:

– ($s, v \geq 0$ and $s > v$) or ($s, v \leq 0$ and $s < v$)



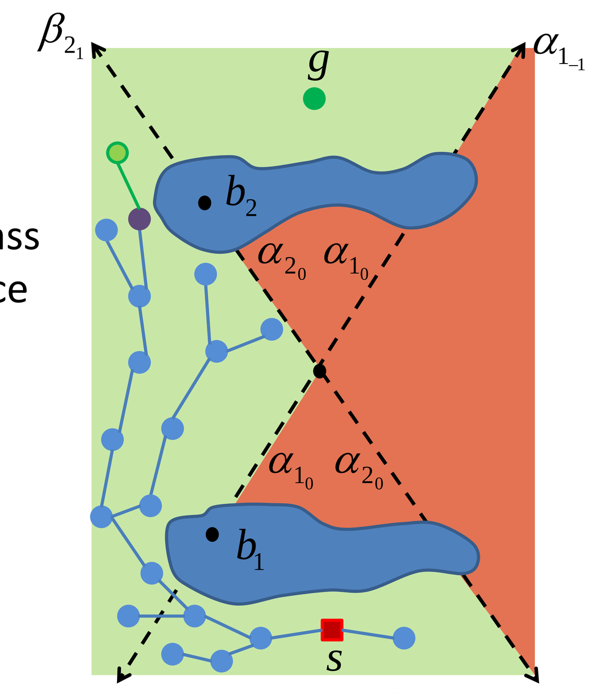
$\chi = (\alpha, \beta)$

3 Homotopic RRT (HRRT)

•**Constrained growing of the tree** into those directions that satisfy the homotopy class

•Adding a new node
 •Nearest node selection criteria:
  •Among nodes closer to the homotopy class
  •The node with the min. Euclidean distance
 •Check intersections with F

•Properties
 •Performance
 •No optimal
 •**Complete within the method**

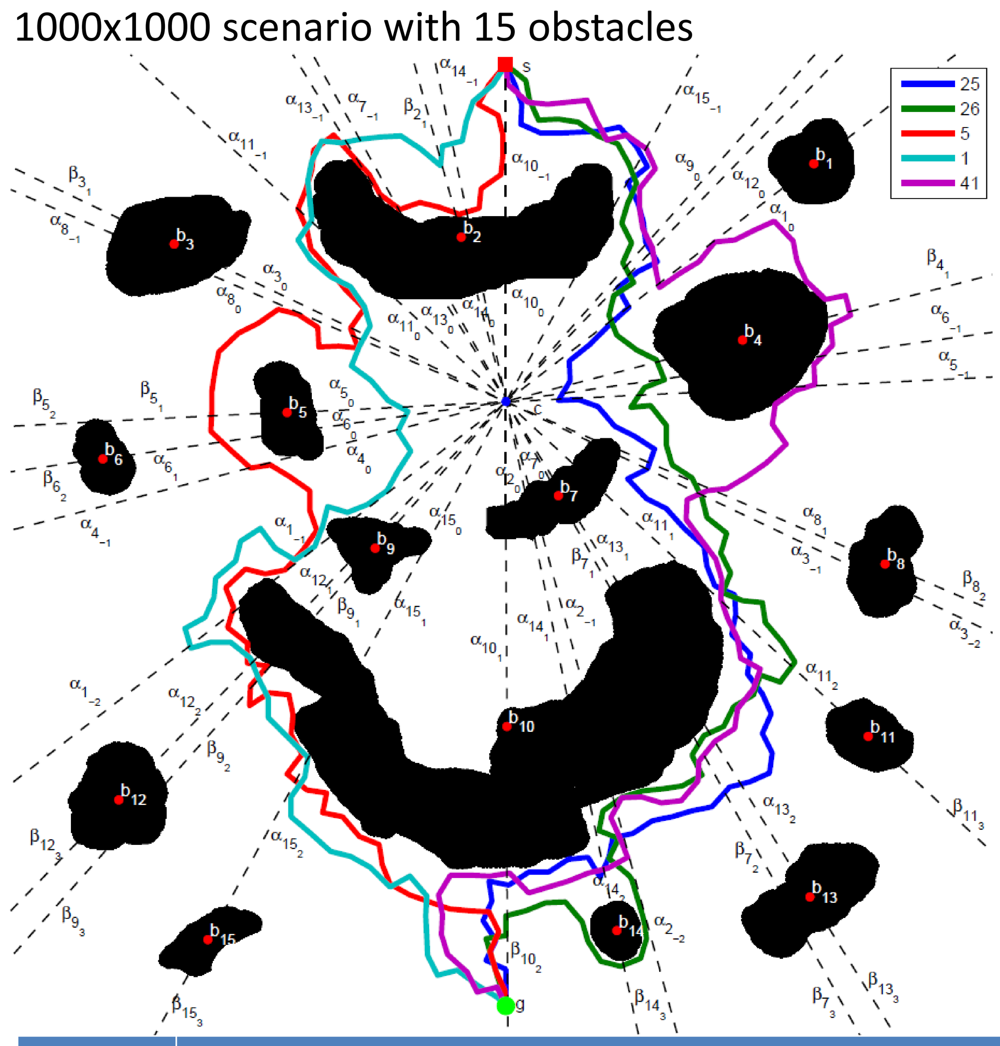


$p = \beta_{1_1}\beta_{2_1}$

4 Results

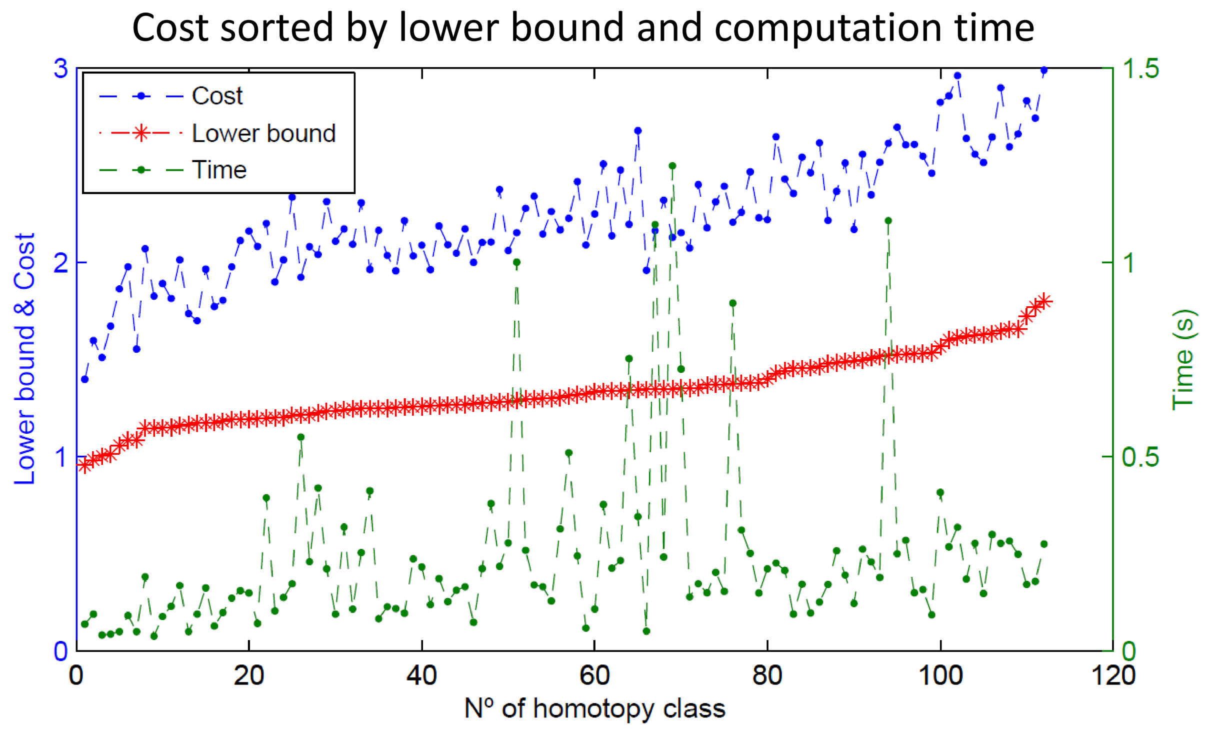
Simulated Results

1000x1000 scenario with 15 obstacles

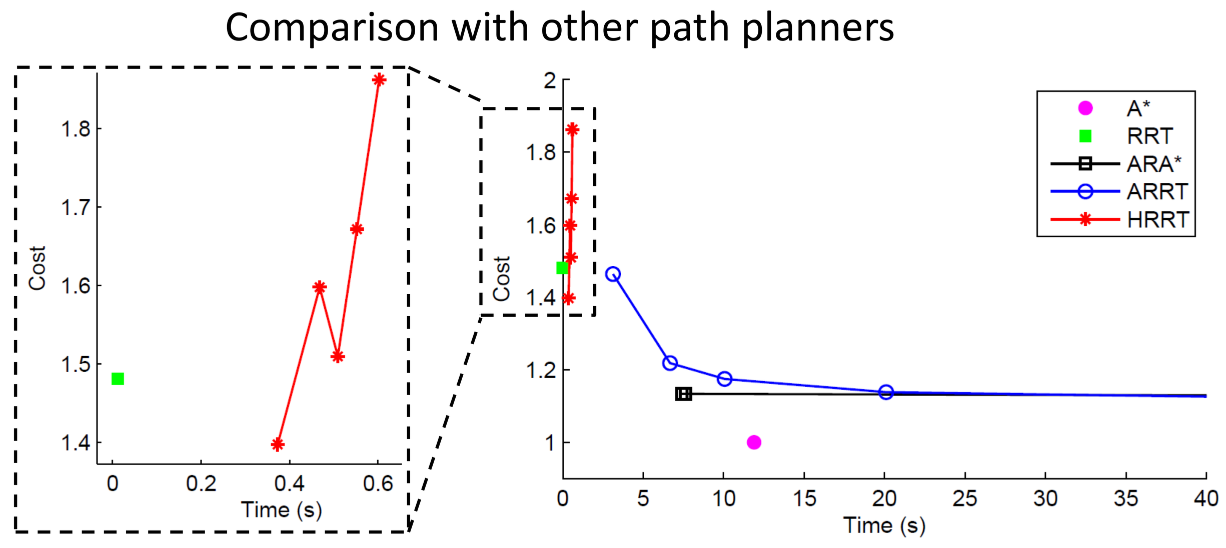


Index	Homotopy class
25	$\alpha_{15_{-1}}\alpha_{9_0}\alpha_{12_0}\alpha_{1_0}\alpha_{4_0}\alpha_{6_0}\alpha_{5_0}\alpha_{8_1}\alpha_{3_{-1}}\alpha_{11_2}\alpha_{13_2}\beta_{7_2}\alpha_{2_{-2}}\alpha_{14_2}\beta_{10_2}$
26	$\alpha_{15_{-1}}\alpha_{9_0}\alpha_{12_0}\alpha_{1_0}\alpha_{4_0}\alpha_{6_0}\alpha_{5_0}\alpha_{8_1}\alpha_{3_{-1}}\alpha_{11_2}\alpha_{13_2}\beta_{7_2}\alpha_{2_{-2}}\beta_{14_2}\beta_{10_2}$
5	$\alpha_{10_{-1}}\alpha_{14_{-1}}\beta_{2_1}\alpha_{7_{-1}}\alpha_{13_{-1}}\alpha_{11_{-1}}\alpha_{3_0}\alpha_{8_0}\beta_{5_1}\alpha_{6_1}\alpha_{4_{-1}}\alpha_{1_{-2}}\alpha_{12_2}\beta_{9_2}\alpha_{15_2}$
1	$\alpha_{10_{-1}}\alpha_{14_{-1}}\beta_{2_1}\alpha_{7_{-1}}\alpha_{13_{-1}}\alpha_{11_{-1}}\alpha_{3_0}\alpha_{8_0}\alpha_{5_0}\alpha_{6_0}\alpha_{4_0}\alpha_{1_{-2}}\alpha_{12_2}\beta_{9_2}\alpha_{15_2}$
41	$\alpha_{15_{-1}}\alpha_{9_0}\alpha_{12_0}\alpha_{1_0}\beta_{4_1}\alpha_{6_{-1}}\alpha_{5_{-1}}\alpha_{8_1}\alpha_{3_{-1}}\alpha_{11_2}\alpha_{13_2}\beta_{7_2}\alpha_{2_{-2}}\alpha_{14_2}\beta_{10_2}$

Cost sorted by lower bound and computation time

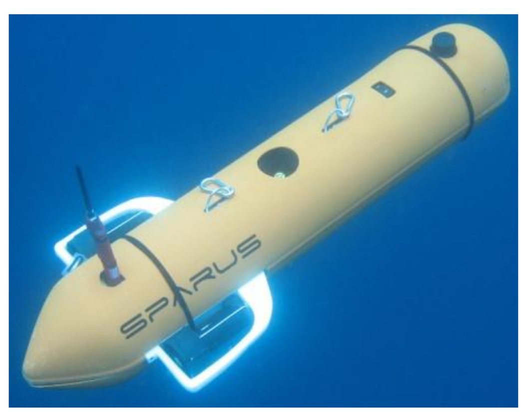


Comparison with other path planners



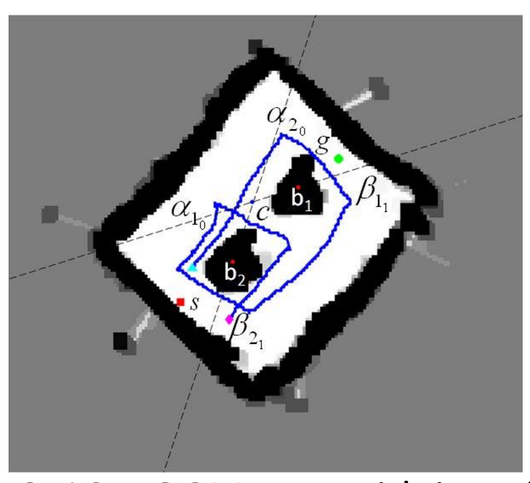
Experimental results

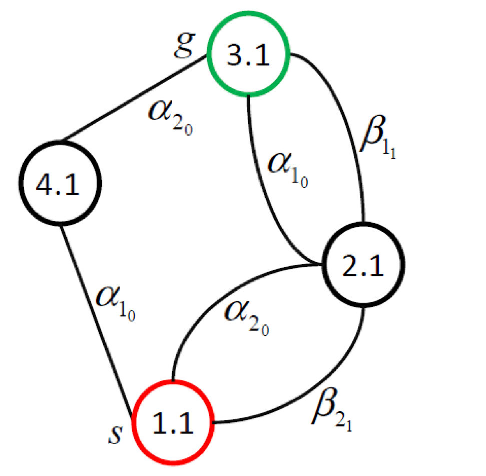
Test with the SPARUS AUV in a water tank



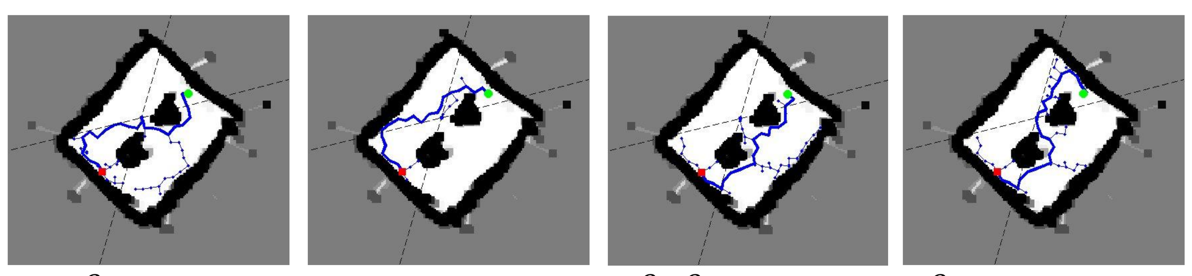
SPARUS AUV

Experimental setup





8x16m OGM map with its reference frame and topological graph



$\alpha_{2_0}\beta_{1_1}$ 13.62m $\alpha_{1_0}\alpha_{2_0}$ 12.42m $\beta_{2_1}\beta_{1_1}$ 11.15m $\beta_{2_1}\alpha_{1_0}$ 14.24m

Computation time < 100ms

5 Conclusions

•We propose a method to generate homotopy classes that can be followed in any 2D workspace
•The homotopy classes are sorted according to a lower bound estimator
•The HRRT computes paths in the workspace following the homotopy classes previously found
•The method has been tested in simulation and with an AUV in a controlled unknown environment

Acknowledgments

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