A Geometric Approach to the Coverage Measure of the Area Explored by a Robot

Maria Luiza Costa Vianna[1,2], Eric Goubault [1], Luc Jaulin[2] and Sylvie Putot [1]

[1] LIX, École Polytechnique, CNRS & Institut Polytechnique de Paris, 91128 Palaiseau, France
{costavianna, goubault, putot}@lix.polytechnique.fr
[2] Lab-STICC - ENSTA Bretagne, Brest, France
luc.jaulin@ensta-bretagne.fr

Keywords: Robotics, interval analysis, exploration, topology

Introduction

Area covering missions are a common task for autonomous robots, where the robot must cover with its embedded sensors or tools a whole area of interest. Estimating the explored area is essential for determining if path-planning algorithms lead to complete coverage. Some applications might also require the robot to revisit an area of interest, in this case, to verify the mission's completion, one has to be capable of determining how many times each part of the space has been in the robot's range of detection. This information can also be exploited in localization, being directly related to the notion of loop closure, a key concept in Simultaneous Localization and Mapping (SLAM) algorithms [4].

In this paper, we propose a solution capable of determining how many times the robot has been sensing each point in the space. Then, using a set-membership approach, we define the explored area as a set of points in the space that were sensed at least once. We use a novel approach based on topological properties of the environment that has been scanned. More precisely, we demonstrate that the computation of certain winding numbers enables to estimate the explored area while also determining the "coverage measure" of each point, i.e. how many times each point in the space was explored by the robot during its mission.

The approach that we propose is adapted to safety-critical applications, where a guaranteed estimation of the robot's explored area is necessary. For this purpose, we use interval analysis to compute guaranteed approximations of the winding number, as briefly outlined in next Section.

Winding number guaranteed computation

In practice, we never have exact robot localization data, so we need to estimate winding numbers around "imprecise" points, that are abstracted using interval analysis. We propose a new method for algorithmically computing the winding number $[\eta]([f], b)$ of the envelope $[f]$ of a continuous function $f : [0, 1] \rightarrow \mathbb{R}^2$ with respect to a box $b \in \mathbb{IR}^2$.

The computation of the winding number using interval analysis is not new, e.g [3]. One of the contributions of this work is that we deal with what we call here uncertain boxes, estimating a guaranteed interval for the winding number value. A box is uncertain if $\exists t \in [0, 1]$ s.t. $b \cap [f](t) \neq \emptyset$: only in this case the winding number is not uniquely determined.

Main results

We propose a new approach for estimating the area explored by a mobile robot. The use of interval analysis makes the approach adapted to deal with uncertainties in the robot's estimated trajectory, making it suitable for safety-critical applications. In comparison to previous works, e.g. [1] and [2], our method estimates how many times each part of the space has been sensed, this is a direct result of the relation established between the winding number and the exploration in the plane. We demonstrated the efficiency of the proposed method using data acquired during a real experience.

Acknowledgement

We acknowledge the support of the "Engineering of Complex Industrial Systems" Chair Ecole Polytechnique-ENSTA Paris-Télécom Paris, partially funded by DGA/AID, Naval Group, Thalès and Dassault Aviation.

References

[**1**] B. Desrochers and L. Jaulin, Computing a guaranteed approximation of the zone explored by a robot. IEEE Transactions on Automatic Control, 62(1):425–430, 2017.

[**2**] V. Drevelle, L. Jaulin, and B. Zerr., Guaranteed Characterization of the Explored Space of a Mobile Robot by using Subpavings. In NOLCOS 2013, Toulouse, France, September 2013.

[**3**] P. Franek and S. Ratschan, Effective topological degree computation based on interval arithmetic, 2012.

[**4**] S. Rohou, P. Franek, C. Aubry, and L. Jaulin, Proving the existence of loops in robot trajectories, 2017.