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Approximate robotic mapping from sonar data by modeling perceptions with antonyms ☆

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ABSTRACT

This work, inspired by the idea of "Computing with Words and Perceptions" proposed by Zadeh in [57,59], focuses on how to transform measurements into perceptions [22] for the problem of map building by Autonomous Mobile Robots. We propose to model the perceptions obtained from sonar-sensors as two grid maps: one for obstacles and another for empty-spaces. The rules used to build and integrate these maps are expressed by linguistic descriptions and modeled by fuzzy rules. The main difference of this approach from other studies reported in the literature is that the method presented here is based on the hypothesis that the concepts "occupied" and "empty" are antonyms rather than complementary (as it happens in probabilistic approaches), or independent (as it happens in the previous fuzzy models).

Controlled experimentation with a real robot in three representative indoor environments has been performed and the results presented. We offer a qualitative and quantitative comparison of the estimated maps obtained by the probabilistic approach, the previous fuzzy method and the new antonyms-based fuzzy approach. It is shown that the maps obtained with the antonyms-based approach are better defined, capture better the shape of the walls and of the empty-spaces, and contain less errors due to rebounds and short-echoes. Furthermore, in spite of noise and low resolution inherent to the sonar-sensors used, the maps obtained are accurate and tolerant to imprecision.

1. Introduction

A commonly required capability of Autonomous Mobile Robots (AMR) is map building. Without a given map, the robot has to navigate, perceive the environment (exteroception), integrate each actual perception with the previous ones, and maintain a coherent and sufficiently accurate representation of the environment. On the one hand, maps can be used as references for navigation, in particular for robot localization and path planning. On the other hand, they can be used as themselves for mapping purposes.

Mapping is an active research area, and there is no final taxonomy of map types. There are several ways to represent a map, for instance, a classical differentiation is between metric and topological maps; metric maps are based on Cartesian reference systems; topological maps emphasize the relations between environmental elements, typically rooms and corridors. This work focuses on metric maps, in particular occupation grid maps, in which the information is represented by

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bidimensional grids. Habitually, each grid's cell corresponds to a squared space region parallel to the floor and at the height of the robot sensors, and it contains the available knowledge about the cell.

Habitual sensors used in indoor AMRs in order to build maps include: odometric sensors (that measure the relative position of the robot with respect to previous ones), and range sensors (that measure the distance to obstacles). Main range sensors are ultrasonic, or sonar, and radial laser sensors. Although laser range sensors offer a greater angular resolution, sonar-sensors have reduced cost, are present on almost every robot platform, and require the computation of a smaller raw data volume.

This work focuses only on sonar exteroception because it suffers from a higher imprecision that other kinds of exteroceptions [6], and therefore an accurate mapping is more difficult to achieve, and because the results could be later extend to other kinds of exteroceptions. An objective of this work is to study how fuzzy logic can help us to manage this imprecision [58,12].

Odometric sensors suffer from some problems [5]; they have a limited resolution and offer incorrect readings when a wheel slips. Consequently, imprecision of odometric estimation grows with distance and number of maneuvers.

Sonar sensing also suffers from several problems [29]; the measure of "time of flight" (TOF) has imprecision inherent in the measuring instrument, it has a poor angular resolution due to the transducers' aperture, and the signal emitted forms an open solid angle which does not permit us to know exactly in which part of the wavefront the obstacle is located [35]. Additionally, if the angle of incidence of the beam in respect to the surface is greater than half of the sensor aperture, the echo may not return, or may return after being reflected on other surfaces. This effect is more likely when the surface is planar and smooth. These kinds of surfaces, such as glass, marble, polished wood, plastic, etc. are commonly found in indoor environments. In general, it can be said that a model of the AMR position based on the distances obtained from ultrasonic sensors is not continuous and not linear.

The specific problem we focus on is how to build an accurate and robust map of the environment by integrating the actual perception with past perceptions [14,3,9]. This problem includes the sub-problem of how to handle sensor noise and the contradictions that arise during the process.

> *"A fundamental difference between measurements and perceptions is that, in general, measurements are crisp numbers whereas perceptions are fuzzy numbers or, more generally, fuzzy granules, that is, clumps of objects in which the transition from membership to nonmembership is gradual rather than abrupt".* L. Zadeh in [57]

The approach taken in this paper is based on the assumption that a perception can be represented by means of linguistic descriptions [59,22], which express imprecise constraints and therefore are gradually satisfied [60,23], and on the hypothesis that occupied and empty are antonyms instead of complementary. In consequence, we propose to build a fuzzy model of obstacles and another of empty-spaces that verify the properties of antonyms.

The main differences of this work with previous ones are:

- It is not assumed that obstacles and empty-spaces are complementary, and that one is the complement of the other, as happens in probabilistic models.
- It is not assumed that obstacles and empty-spaces are independent as happens in previous fuzzy models.
- We assume that obstacles and empty-spaces form a pair of antonyms and should be modeled as such.
- It is not assumed that observations are independent as happens in probabilistic models, in fact some observations are used to correct others.
- It is not assumed that the exact position of the robot is know, so there is imprecision about it. So the model should tolerate that imprecision and still produce robust maps.
- We dealt with rebounds, short-echoes, and other noises by defining a set of fuzzy rules that capture our knowledge about the problem.
- The way of building the aggregated maps by means of linguistic quantifiers differs greatly from previous approaches, and it allowed us to handle the partial contribution of each sonar reading to the aggregated map.

The main contributions of this work are:

- A robust model based on antonyms that can properly handle the imprecision and contradictions that arise in the process of building navigation maps.
- The antonyms-based model allows to discard rebounds and short-echoes and reduce greatly the contradictions and errors. Also, by dealing explicitly with contradictions, this model is able to distinguish between two kinds of unknown cells, the ones that are unknown due to contradictions and the ones that are unknown because are unexplored. This allowed to the robot to recognize which zones needed to be navigated with care and which ones needed to be explored later on.

The maps obtained by the antonyms-based method are better defined, capture better the shape of the walls and of the empty-spaces, and contain less errors due to rebounds and short-echoes. The use of approximate maps allowed us to synthesize the accumulated information from samples in a way that kept the data structure constant while the accuracy of the representation increased with the number of samples. The proposed method obtains better maps with higher con-