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The centre of area method as a basic mechanism for representation and navigation

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Abstract

Potential methods and all their gradient-based derivations are extensively used in autonomous robotics, primarily in association with reactive navigational strategies. In this article we introduce the fundamentals, formalisation and application of a brand-new method based on first-order moments called the "centre of area method". We also comment on its validity, at an individual level and in combination with other methods, in order to build a situated representation of the environment.

Keywords: Autonomous robots; Centre of area; Spatial representation; Roadmaps

1. Introduction

From 1985 to date, numerous techniques have been proposed for the navigation of autonomous robots in potentially unknown and dynamic environments, using reactive or deliberative methods, with or without an explicit representation of the external environment in the robot's memory, and always trying to achieve the greatest degree of autonomy [1]. One of the first attempts, based on Mathematics, was called the configuration space (C-Space). In this proposal the real space where the robot moved was transformed into a dual space where the robot was a point and the obstacles increased according to the robot's size and orientation. This transformation made it possible to use navigation techniques called roadmaps, like the Voronoi diagrams or Repulsive potential methods (VFF). The Voronoi diagrams (see Fig. 1(a)) [2], based on a technique also mathematically inspired, applied to a C-Space (although they can also be applied in the workspace), result in a series of lines called "locus" that are equidistant from all the obstacles. These lines can be used as safe paths for the robot's navigation. The "Virtual Force Field" (VFF) methods (see Fig. 1(b)) [3, 4], inspired by Physics, can be used with or without C-Spaces and are based on the application of the physical laws of central potentials (electrostatics, gravitation). The robot and obstacles are considered as charges of a same sign which repel one another, and the target that the robot must reach as an opposite charge sign that attracts the robot. The robot's movement is therefore a simple vector sum of the forces applied to the robot, whose movement is given by the direction and orientation of the resulting force [5].

These and other techniques have finally been used as tools in more complex architectures [6,7] that aim to cover these methods' deficiencies, since efficient navigation is impossible without an injection of external knowledge. Other approaches exist to solve the environment-modelling problem, such as those based on probabilistic methods [8,9], but they are beyond the scope of our proposal.

Our centre of area method proposed [10–15] here can be considered as a development of these techniques. On the one hand, there is a transformation of the space, with relative local invariances, where the robot moves at a dual space and where, although the robot is not considered as a point, the robot is only allowed to move along certain points in the space and not in others. In this space, governed by the centres of area, we can detect and establish safe paths for the robot's movement, similar

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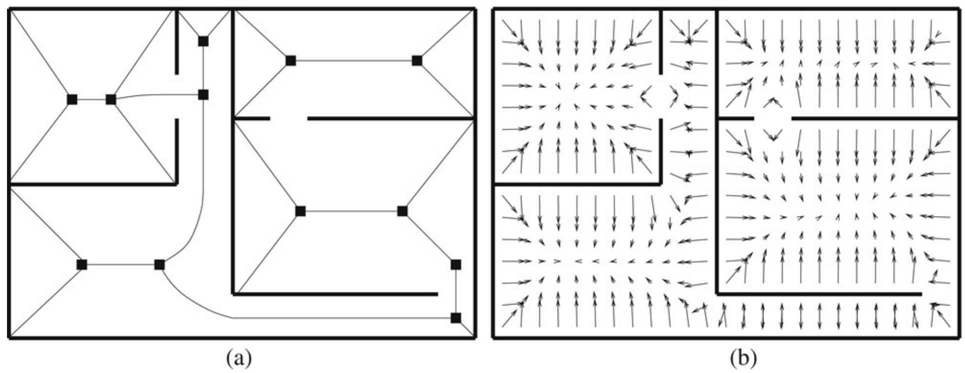

Fig. 1. Space representation types using methods: (a) Voronoi diagram (locus and graph nodes) and (b) virtual force field (VFF) (without a target).

to the Voronoi diagrams, and we can also use the properties of the centres of area inspired by Physics, similar to the VFF, for the robot's movement.

Our method is not a definitive solution to the navigational problem either, but just another tool that has to be complemented with external knowledge, as we will see at the end of the section on its use. Our aim in this work is not to completely solve the problem of environment modelling with an autonomous robot, but to introduce a new modelling tool, which combined with other tools, may be used to obtain a complete solution, as shown in a number of our previous works [11,13].

The aim of this method is therefore movement guided by the centre of area of the free space detected. This movement is performed in an *a priori* unknown environment (without a previous map or landmarks) and even takes into account possible changes (doors opening and closing), and objects moving.

Before describing the centre of area concept, we will first describe how to store the information captured by the robot's sensors on the local neighbouring environment around it in an appropriate representation, so that we can extract geometrical properties that are approximately invariant with respect to small changes in the local position.

2. Open surrounding space representation

We need a representation for an open space around the robot that is time persistent and accumulates information from the sensors as it moves. The representation to be used is influenced by and is relative to the robot's environment context. This context will affect the assumptions and simplifications of environment representation and model. For example, even if we do a full 3D representation of a rough terrain and have no sensors directed at the floor, we will have to suppose that the terrain is "approximately" flat, and points in this direction will be estimated from assumptions included in the environment model (not by sensor readings). In other words, when a robot is designed for a task in an environment, the sensors that are needed and their location have to be taken into account to enable us to represent the environment appropriately for the task.

In the examples and nomenclature used below, we mainly use a 2D representation of a 3D space essentially distributed on a plane ($2D\frac{1}{2}$), although the calculations and notations are easily extensible to a full 3D representation.

2.1. Real range sensors

They are directional sensors returning as information, at the reading instant, the measured or estimated distance to the nearest detectable object within their range, depending on their current orientations.

The returned distance is always an indirect measurement extracted from the estimation of a model which depends on the sensor type. The infrared sensors most frequently used are based on the intensity of light reflected by an object with respect to the light intensity emitted (the inverse of the distance square). On the other hand, typical sonar sensors are based on the round-trip flight time of a reflected ultrasonic pulse train emitted by a membrane (lobe transmission models), and normal laser sensors are based on the interference between an emitted beam and reflected one, or on polarisation and reflectance models. We may consider several degrees of simplification for these real sensors depending on the environment complexity, robot type and task to be performed. In any case, these calculations and simplifications are attached to the sensor. In this work we consider them to be part of the sensor detection procedure and the information we thus use is the corresponding distance.

2.1.1. Detection field width and sensitivity

Sensors may detect objects inside a limited width cone whose vertex is centred on a sensor point. Sensitivity and reliability (via internal model estimations) can vary according to the distance from the object detected. Simplifying, the most common procedure is to consider the measured distance as isolated (and exact), but the field width and sensitivity could also be taken into account and an error range could be included in every measurement representation.

2.1.2. Position and orientation with respect to the robot

The robot's sensors can be fixed or movable (limited) with respect to the robot's body. Sensors are usually in fixed positions, but they can change their orientation. Given that we are interested in detecting obstacles around the robot, sensors are primarily oriented towards the outside of the robot. The simplest extreme case is for every sensor to be fixed and radially