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Reactive navigation in real environments using partial center of area method

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ABSTRACT

Using inspiration from our perception on how humans select the path to walk in crowded areas, a new method for reactive autonomous robot navigation is proposed. The method uses only a part of the detected free space in front of the robot to compute a partial center of area. It can guide the robot safely for robust wandering while the center of area remains accessible. In some cases it is necessary to split and shrink the detected area used for navigation to overcome a transitional inaccessible center of area. The method was slightly modified so that the robot can reach a stimulus goal while avoiding obstacles. Method implementation and modifications are explained in detail. Some experiments were carried to test the method with a real robot in mid-complex environments. In previous works the method was extensively tested in simulations and the good results obtained there are confirmed by the real robot tests.

1. Introduction

In previous works the center of area of free space around an autonomous robot was used to control the robot movements [1–3]; we also explored its mathematical backgrounds [4]. Those methods used the center of area position as attraction or repulsion point alternatively by using different behaviour modes in robot control. The invariance properties of the center of area are very interesting for map navigation, but they require the use of high level control with topographical maps built during movement [5]. The aggregation nature of center of area makes difficult to use it as the only guide for movement through some complex environments.

In [6] we start a new line of research consisting in using only a part of the detected free space around the robot to compute a partial center of area for space representation. Then this partial center of area can be used to guide the robot in an efficient wandering inside unknown and complex environments, and also as base for obstacle avoiding movement with goal attractor stimulus. In both cases robot movement totally depends on center of area movement, it uses only reactive information from the sensors, and outperfoms some difficult situations for potential methods [7].

This line of research is inspired by a working hypothesis: humans mainly model the free surrounding area, not the occupied area (obstacles), when doing reactive navigation, and we use its center of area as a reference for movement. This hypothesis and its relations with method implementation details will be fully exposed in Section 2.1. Section 2.2 describes our solution for the main issue when using the center of area as a movement reference: inaccessible centers of area. We basically propose a shrinking/splitting procedure of the perceived area to try to find accessible centers of area. Section 2.4 contains the explanation of the procedure for goal reaching using the proposed method. Section 2.5 shows our implementation for "using the center of area as a movement reference", given empiric kinetics formulae. To finalize the method description, Section 2.6 comments method performance summarizing previous simulated experiments.

Section 3 gives a description and the results of our real robot experiments to seek for and to reach a visual target using a video camera attached to the robot in a complex unstructured environment, using the center of area method for reactive navigation. In this work it is not our aim to develop a robust procedure for visual tracking, but only to test our method in real environments, in order to better know about its goodness and drawbacks.

Conclusions and work in development are drawn in Section 4.

2. Method description

2.1. The working hypothesis

Seeking for inspiration sources in the way humans solve the problem of finding the correct way avoiding obstacles, first we can imagine the situation where we are driving a car, while we see a big truck coming in the opposite direction (see Fig. 1(a)). In such a

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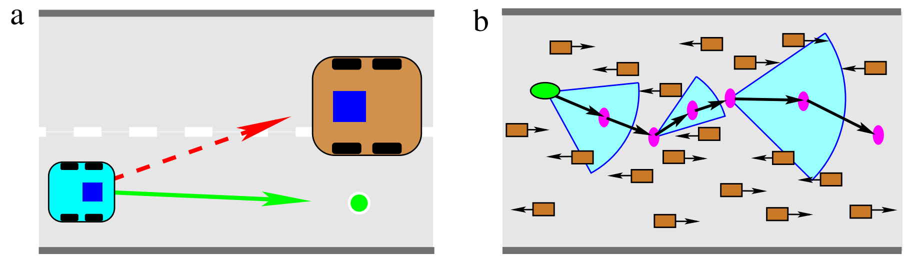

Fig. 1. Some inspiration sources for the working hypothesis. (a) When driving a car while a big truck comes in the opposite direction, it is better to look at the space. (b) Human reactive navigation when walking in a hurry across a crowded street. Rectangles represent other people walking. For each section of our way we tend to seek the center of free space near our way (represented by small ellipses inside the circular sectors).

situation, a good advice for novice drivers is: "Look at the space, not the truck!". We can also remember how we proceed when we are walking in a hurry across a crowded street (see Fig. 1(b)). For each section of our way, we reactively look for and follow the center of area of surrounding free space, modelling this free area as a function of environment distribution. Crowded areas makes us look down and, thus, decrease our speed and, on the other hand, clear areas allow us to look up so we can increase our speed.

The working hypothesis, as we stated in the introduction, is: humans mainly model free surrounding area, not occupied area (obstacles), when doing reactive navigation, and we use its center of area as a reference for movement. More precisely:

- Humans compute and follow, approximately, the center of area of a sector of the free perceived surrounding frontal area, lets call it "advance sector".
- The advance sector is roughly a circular sector with variable radius, start and end angles. Radius and angles depend on the spatial advance sector configuration. For more crowded surrounding areas, then the sector, radius and/or aperture must be smaller.
- After sector selection, we orient ourselves in order to put the advance sector in a frontal position. Then we follow the center of area with a speed related to the distance to it (e.g. nearby centers of area limit maximum speed).

In the following sections we use these ideas as starting points to develop a procedure and an implementation for safe reactive robot navigation.

2.2. The split process for inaccessible centers of area

Navigation through convex areas is safe, the line between every two points of the area is fully contained in the area, that is, convex areas has no obstacles inside, although they have limiting ones. In this sense the center of area of a convex area is the safest place in the area, far away from limiting obstacles. Thus turning to the center of area and going straightforward to it is the safest option to take. This reasoning is a support for the first and third item of our working hypothesis. This reasoning works for the theoretical case of a fully sensed world as for the real one, where only a small area of the world is perceived, whenever the perceived area covers movement direction.

The problem arises when a perceived area is not convex. In this case, the center of area can lie outside it and become inaccessible, so it is impossible to reach the center of area. Basically, our solution to this trouble is to split the perceived area in two, with the hope that some of both parts has an accessible center of area to go towards it. Fig. 2(c) shows an example of a non-convex area split in two convex ones.

This idea comes from living situations as in Fig. 1(b). Also, in those situations, we observed that people tend to look down while changing their path due to obstacles. We added this idea to the area split process, shrinking the resultant areas before centers calculation, by means of a limitation in the maximum considered range for the sensors. In addition, the shrinking process could yield areas with less noticeable concavities, thus with a larger probability of having an accessible center of area. By the moment, and for exposition simplicity, the robot is considered as a mathematical point, then accessible point means the same as point contained inside the perceived area, later we will deal with robot dimensions, see Section 2.3.

With this ideas in mind we can draw the process for finding accessible centers of area for safe navigation, depicted in Fig. 2. The full frontal perceived area will be called the full advance sector and the result of any splitting or shrinking operation will be called restricted advance sector. When using range finders the perceived free area may be seen as a polygon, more precisely a star-shaped polygon. Polygon vertexes are a subset of range measures and the robot local coordinates system origin, from now on, to avoid repetitions, the origin is considered as vertex of every polygon or sector without mention. Local coordinates are the only reference system used for the center of area method. Now the method description:

1. Robot starts in a position where the center of area of its full advance sector is accessible,[1] in our experiments this sector has an aperture of 180°, then robot starts to follow the center, see Fig. 2(a).
2. While the center of area is accessible the robot follows it, see Fig. 2(b).
3. When the center of area becomes inaccessible, determine the two consecutive polygon points defining the angular sector containing the line from the origin to the center of area. Choose the closest point to the origin as the split point and split the polygon in two. Shrink both polygons, e.g. use half maximum sensor range, calculate their centers of area and determine their accessibility, see Fig. 2(c).
   - If both centers are accessible choose one of them, randomly or by external preference.
   - If only one center is accessible choose it.
   - If both centers are inaccessible, no way, determine the center of area of the robot shrunk rear area and turn to it as a escape manoeuvre. The polygon corresponding to the selected center of area is the restricted advance sector. The split point local coordinates have to be stored in a short-term memory and they have to be updated using robot raw odometry. The robot almost stops and starts to turn to the selected center of area. As robot turns, update split point coordinates. Also, vertexes of the discarded polygon are moving to the side of the split point, where the selected

[1] In our exposition, for the sake of simplicity, the center of area is accessible at the beginning, but this is not a mandatory condition.