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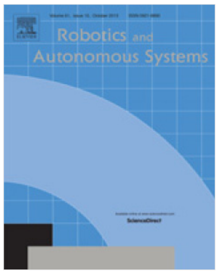

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Cooperative Mapping of Unknown Environments by Multiple Heterogeneous Mobile Robots with Limited Sensing

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Abstract — While recent advancements in using sophisticated onboard sensors on robotic platforms has made it possible to consign various tasks like exploration, mapping, and flocking to teams of mobile robots, some issues like handling extensive amount of data, high dependency on sensors' performance, and high expenses emerge. In this paper, the problem of mapping unknown environments by a team of heterogeneous mobile robots with limited and inexpensive sensing abilities is addressed. The concepts of Information Space and sensor models have been employed to plan the motions of robots with limited sensory data in order to accomplish the common goal of mapping the entire workspace as complete as possible. Also, a cooperation architecture is proposed to fuse and interrelate the dissimilar data obtained by individual heterogeneous robots and allocate various exploratory tasks to each of them in order to complete the map. The algorithm works with various limited sensing model, such as depth-limited boundary distance sensor, quadridirectional depth sensor, depth-limited gap sensor, and depth-limited radially-bounded depth senor. Based on each sensor model, the best moving strategy is introduced to maximize the workspace coverage for each robot. The proposed algorithm, which yields a geometric map of the environment, is implemented in diverse simulated problems both with and without sensing noises, and the results and comparisons with a recent related work show that it is able to reliably construct maps of simply-connected and multiply-connected environments with convex and concave obstacles. In presence of noises, the produced maps had about 12.4% false positive and 3.3% false negative errors on average. Also, some sensitivity analyses are done on the effects of workspace size and number of robots on the mapping time.

Keywords: Mapping; Limited Sensing; Unknown Environment; Information Space; Multi Robot Navigation.

1. INTRODUCTION

Research in robotic navigation has been focused on three major tasks: localization, mapping, and path planning. In localization the robot tries to estimate its position accurately in an unknown environment, in mapping a presentation of environment that is a one-to-one transformation of the world is created, and in path planning a collision-free path is calculated from an initial to a goal position. While mapping itself is a separate research subject in robotics, it is mostly used as a preprocessing step for higher-level tasks (such as planning, covering, foraging, flocking, etc.) performed in unknown environments. In the absence of a map, motion or task planning must be based on local sensing, and the map of the environment has to be built incrementally, which results in non-optimal or locally-optimal solutions. For building a map of an unknown environment, adopting a good search strategy based on sensing features of robots is important. The more accurate and complete is the sensing, the more successfully the task will be accomplished. For instance, laser scanners have many advantages over sensors of other types like sonar, infrared, or vision: they provide dense and more accurate range measurements, have high sampling rates, high angular resolution, and good range distance and resolution (Borenstein *et al.*, '96). 2D and 3D laser range finders are becoming increasingly popular in mobile robotics, as in feature extraction in outdoor environments (Adams *et al.*, 2004), feature tracking (Anguelov *et al*., 2004), map-building of cluttered environments (Wulf *et al*., 2004), and collision avoidance in dynamic environments (Masehian and Katebi, 2014).

Mapping in unknown environments can be performed by a single robot or multiple robots. One of the first works on mapping unknown environments using a single robot was a sensor-based mapping and motion planning method presented in (Elfes, 1986), which provided a multi-level description of the environment. On the other hand, the first work on mapping by multi robots seems to be (Singh and Fujimura, 1993), which represented an algorithm for collaborative mapping using occupancy grid for a team of heterogeneous robots.

There are two major ways of representing objects in an indoor environment: *Geometric* and *Topological* (Borenstein *et al*., 1996). In a geometric map, objects are represented according to their absolute geometric

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