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Editorial

Special Issue on Mobile Robots Navigation

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1. Introduction

In recent years, the presence of mobile robots in diverse scenarios has considerably increased, to solve a variety of tasks. Among them, many developments have been carried out over the past few years in the fields of ground, underwater, and flying robotics.

Independently on the environment where they move, navigation is one of the fundamental abilities that mobile robots must be endowed with, so that they can carry out high-level tasks autonomously, in a specific environment. This problem can be addressed efficiently through the following actions. First, it is necessary to perceive the environment in which the robot has to move, and extract some relevant information from it (mapping problem). Second, the robot must be able to solve the localization problem within this environment (localization problem). With this information, a trajectory towards the target points must be planned (path planning), and the vehicle has to be guided along this trajectory, in a reactive way, considering either possible changes or interactions with the environment or with the user (control).

To perceive the environment, some kinds of onboard sensors can be used, such as laser rangefinders, visual systems, or RGB-D platforms. This perception task can be carried out either beforehand or once the navigation task has started, while the robot moves through the environment, and the result is a model or map of the environment. Regarding the localization task, it must be designed considering several issues: the available sensors, the structure of the map, and the movement constraints that the robot presents (i.e., trajectories in 3D or 6D). Furthermore, integrated exploration systems consider all these issues jointly, and they develop trajectory planning and control, while a model of the environment is obtained, and the robot estimates its position and orientation within it.

Finally, the existence of versatile tools to simulate any new development in mobile robots navigation is crucial to quickly test and compare navigation algorithms.

In light of the previous information, this special issue was introduced to present current frameworks in these fields and, in general, approaches to any problem related to the navigation of mobile robots. There were 39 papers submitted to this special issue, from which 14 papers were accepted (i.e., 36% acceptance rate), which addressed a variety of topics, as detailed in the next sections.

2. Map Building and Localization of Mobile Robots

In most applications, mobile robots have to move through a priori unknown environments. Therefore, it is often necessary either to have a partial knowledge of the surroundings of the robot or to build a more complete model or map of this environment that can be used, subsequently, to estimate the position and orientation of the robot and to plan optimal trajectories to the target points, in such a way that the robot can autonomously move and perform the task which it has been designed for.

Occupancy grids constitute a traditional and efficient mechanism to represent the environment. In this respect, Distance Maps (DM) are a widely used tool to encode the search space in robotics path planning and obstacle avoidance, as they can provide the robot with a certain safety radius to efficiently search out collision-free paths and to avoid obstacles in motion. In this field, Qin et al. [1] propose an efficient algorithm (Canonical Ordering Dynamic Brushfire (CODB)) to incrementally update the cell values when cell states are changed (due to changes in the environment). It requires fewer cell visits and computation costs than previous algorithms. They also propose an algorithm to compute DM-based subgoal graphs which are able to provide high-level collision-free roadmaps for the mobile robot. Finally, they verify that optimal trajectories can be obtained with these subgoal graphs and a real-time search algorithm.

Zhu et al. [2] focus their study on multilegged walking robots. Their redundant limb structure usually confers them good stability and maneuverability even in complex environments. However, their ability to perceive the surrounding environment impacts upon their autonomous mobile ability. One of the critical issues is the accurate terrain identification. The authors propose an image infilling method for terrain classification based on a Bag-of-Words (BoW) approach, Speeded-Up Robust Features and Binary Robust Invariant Scalable Keypoints (SURF-BRISK) and Support Vector Machine (SVM). In broad lines, the obstacle regions are infilled by surrounding terrain to improve the classification accuracy, a super-pixel image infilling method for mixed terrain is developed and multiple labels can be given to complex terrains. Their experiments show the validity of the approach in mixed terrains and terrains with obstacles.

The exploration problem is closely related to the mapping problem. It tries to discover unknown areas of the environment to add them to the map so that the robot can have a more complete knowledge of the surroundings. Kamalova et al. [3] develop a method to explore unknown indoor environments, with the purpose of building a model of them. They approach the problem as a multiple-objective exploration, using the Multi-Objective Grey Wolf Optimizer (MOGWO) algorithm, which employs static waypoints in the process, promoting the efficient exploration of indoor environments. The philosophy of this exploration process is to optimize both the search of unexplored areas and the accuracy of the map. The simulation results show the ability of the approach to build complete maps, comparing to deterministic and hybrid stochastic exploration algorithms.

As far as mapping and localization are concerned, hierarchical models play an important role. They arrange the information of the environment into several layers with different levels of granularity, which permit solving the localization problem efficiently. Cebollada et al. [4] concentrate on this topic, and propose an algorithm to compress topological models in order to create the high-level layer of the map, by means of a clustering approach. They use omnidirectional images and global appearance descriptors. The experiments show the efficiency of the algorithm to create compact hierarchical models and to solve the problem of visual place recognition with a good balance between computation time and localization accuracy.

Continuing with the localization problem, another relevant issue in mobile robotics is the incremental estimation of egomotion from the exteroceptive sensors the robot is equipped with, typically visual sensors. This problem is commonly known as visual odometry (VO). In this regard, the work by Song et al. [5] presents a Visual-Inertial Odometry approach, based on the cubature information filter and H_∞ filter, namely, $MCH_\infty IF - VIO$, which uses a raw intensity-based measurement model for the camera. On the one hand, the measurements from the IMU (Inertial Measurement Unit), and the camera are fused by means of a hybrid information filter, which applies two cubature rules in the time-update and the measurement-update phases, to guarantee numerical stability. On the other hand, the H_∞ is used in the measurement-update phase to achieve robustness against non-Gaussian noises in the camera measurements. The authors validate their proposal experimentally, with a publicly available outdoors dataset, comparing its performance to other previous approaches.

Finally, disposing of versatile tools that enable researchers to quickly test and compare navigation algorithms in real operation conditions is key in autonomous mobile robotics. In this field, Muñoz-Bañon et al. [6] develop a framework for fast experimental testing of navigation algorithms in autonomous robotics, which is based on the Robot Operating System (ROS). They provide a basic structure arranged into a number of abstraction levels that allows researchers to implement and test their algorithms, focusing in any sub-problem of interest such as mapping or localization. The paper proves the validity of the framework by showing how to implement the localization module of a ground robot which uses global navigation satellite system positioning, and Monte Carlo localization with a Kalman filter, and is tested with large outdoor environments.

3. Path Planning and Motion Control

Once a local representation or a complete map of the environment is available, the robot can focus on the planning of optimal trajectories and the motion control to carry out a specific task or series of tasks, considering a set of constraints that will depend basically on the tasks, the architecture of the robot and the environment where the robot has to move.

Sun et al. [7] set their sights on the path planning problem, more concisely, on Artificial Potential Field (APF) approaches. They are an efficient alternative for motion planning in mobile robotics, but they are often limited by the presence of local minima in which the robot may get trapped. For this reason, they propose an improved version of this method (Dynamic APF (DAPF)), which uses a dynamic window approach to avoid local minima regions. Additionally, they address the problem of dynamic obstacles avoidance by means of a danger index which does not only consider the relative distance between robot and obstacle but also their relative velocity. The experimental section proves the ability of the algorithm to find optimal paths that avoid both local minima and moving obstacles.

Zeng et al. [8] present a two-level hierarchical framework for robot navigation in dynamic environments in a continuous way, named JPS-IA3C (Jump Point Search Improved Asynchronous Advantage Actor-Critic). On the one hand, the global planner JPS+ (P), which is a variant of JPS, efficiently computes a sequence of subgoals for the motion controller, which can eliminate first-move lag and avoid local minima. On the other hand, the low-level motion controller IA3C learns the control policies of the robots' local motion to satisfy the kinematic constraints and adapt to changing environments (moving obstacles). Additionally, IA3C builds a novel reward function framework, which avoids learning inefficiencies dues to sparse reward. The authors perform a set of simulation experiments that prove that this hierarchy is able to cope with incomplete and noisy information, and navigate robots in unseen and large environments with shorter path lengths and low execution time.

In some applications, the collaboration between the members of a team of robots can be of interest. Bae et al. [9] propose a multi-robot path planning algorithm that tries to overcome some of the shortcomings of conventional methods, such as the adaptation to complex and dynamic systems and environments. In multi-robot navigation, depending on the situation of the mission, each robot can be seen either as a moving obstacle which performs independent actions or as a cooperative robot that collaborates with other robots. To address these issues, the proposal of this paper consists in a framework based on the use of deep q learning combined with Convolutional Neural Networks, using visual information from the surrounding of the robots. The simulation results prove the flexible and efficient navigation provided by the method.

Liu et al. [10] present a method for path planning oriented to Unmanned Surface Vehicles (USV), which takes into account the risk of water depth. This is a crucial factor for the safe navigation in shallow waters. With this aim, the authors study the stability of USV's in a variety of situations and calculate the minimum safe water depth. To plan the path, a Water Depth Risk Level A* algorithm (WDRLA*) is proposed, and its performance is compared with the traditional A* shortest path and safest path. The authors use the depth point of the Electronic Navigation Chart (ENC) and a spline function interpolation algorithm to obtain a grid environment model considering water depth. The numerical simulations prove that the algorithm guarantees navigation safety in different conditions.

Zhao et al. [11] focus their work on space robotics, which are designed to work in outer space in a variety of tasks, such as assembly and maintenance of space stations. In this kind of robots, the Multitask-based Trajectory-Planning Problem (MTTP) is of utmost importance, as it would enable the robot to perform two or more tasks in each mission, what would suppose a save of energy. The authors use piecewise continuous sine functions to create the trajectories along the waypoints and transform this problem into a parameter optimization, using an improved genetic algorithm to optimize the unknown parameters. Numerical simulations are carried out with a base spacecraft and a 7-degrees of freedom manipulator in two simulation cases, and they prove the efficiency of the approach.

Trajectory planning is also a relevant technology for autonomous Unmanned Aerial Vehicles (UAV). Majeed et al. [12] propose a flight path planning algorithm to find collision-free, minimum length and flyable paths for such vehicles in three-dimensional urban environments with fixed obstacles, for coverage missions. This problem consists in finding a low cost path that covers the free space of an area of interest with minimum overlapping. The authors address this problem based on a novel footprints' sweeps fitting method. They generate a sparse waypoint graph by connecting footprints' sweeps endpoints considering the obstacles, maneuverability constraints and footprints' sweeps visiting sequence. Simulation results prove the good performance of the algorithm in a variety of scenarios.

In the field of movement control of legged mobile robots, Yang et al. [13] aim attention at the problem of energy consumption, as it can be considered a performance index of quadruped robots. In their work, they model and analyze the energy consumption of the robot SCalf with a trot gait, and they study the effect of different gait parameters, such as step length, gait cycle, step height, and duty cycle. The experiments show which is the optimal choice of these relevant parameters, as far as energy consumption is concerned. To this purpose, the authors build the dynamics model of the robot, based on an analysis of the foot force distribution and derive a complete energy model which includes mechanical power and heat rate. Also, they use a foot trajectory based on cubic spline interpolation to describe the motions of the robot.

Finally, path planning is also a crucial problem in the field of industrial robotics. The work of Guo et al. [14] concentrates on the field of industrial manipulator robots, more concisely on machining and fabrication applications, among which deburring plays an important role. They develop a hybrid manipulator robot with five degrees of freedom. Also, they propose in the paper a deburring framework focusing on tool path planning (position and orientation) and robotic layered deburring planning; and a process parameter control based on fuzzy logic. A variety of experiments are performed to prove the dexterous manipulation and the orientation reachability of the manipulator and to verify the effectiveness of the two proposed methods in a deburring process.

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