Safe Operation of Autonomous Mobile Robots in Human-shared Industrial Workspaces

I-RIM Conference 2019
October 18 - 20, Rome, Italy
ISBN: 9788894580501
DOI: 10.5281/zenodo.4793413

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***Abstract*—This extended abstract overviews some solutions developed for the safe operation of Autonomous Mobile Robots (AMRs) in human-shared industrial workspaces: a supervised global planner and the adoption of AMRs acting as meta-sensors to detect the human presence, and share the information with other mobile agents or traditional AGVs operating in the plant.**

***Index Terms*—Mobile robots, path planning, obstacle avoidance, sensor data fusion.**

I. Introduction

Industrial applications using Autonomous Mobile Robots (AMRs) are increasing in recent years, since they are suitable to work in dynamically changing environments shared with human operators, thanks to the presence of heterogeneous on-board sensors. AMRs can be considered as an evolution of the traditional Automated Guided Vehicles (AGVs), with additional features, such as the ability to robustly sense their surroundings.

The solutions presented in this work, which have been developed within the HuManS – Human-centered Manufacturing Manufacturing Systems project, funded by Regione Piemonte, try to meet the Industry 4.0 requirements. From this perspective, the industrial environment is uprooted from its traditional constraints with an approach that will be more and more *anthropocentric*, given the upcoming developments that foresee robots and humans working synergistically in the same ecosystem. A new focus is thus addressed to the human operators safety.

A three-levels global planning algorithm is proposed to let a mobile platform perform path following of a safe set of waypoints generated by a supervisory planner. The safest (not necessarily shortest) path generated at the highest level is set as a constraint, and integrated with information coming from the lower levels of planning, updating accordingly the initial plan [1], [2]. Furthermore to meet the need for flexibility in the future production line model, the possibility of using a fleet of AMRs as a support to AGVs, centralizing the processing of the data obtained from multiple sensors on-board of such AMRs [3], leads to a distributed sensorization of the plant, fostering adaptation and the possibility of bringing back to light pre-existing obsolete systems [4].

II. Materials and methods

In order to develop and preliminarily test the proposed approaches in a laboratory environment, we employed a Pioneer 3DX mobile robot [5] equipped with a SICK LMS-200 laser range finder [6]. An entry level IP camera [7] has been added to enable computer vision algorithms. As a processing unit for control purposes and data receiving, we used a Raspberry Pi [8] 3 Model B; the code that required a higher computational effort has been run on a desktop PC mounting a Intel Core i7-7700 CPU and a dedicated GTX1060/6Gb GPU.

A. Supervisory path planning

The proposed path planning algorithm is composed of three levels: the Supervisory Global Planner (SGP), the Global Planner (GP) and the Local Planner (LP) [2]. Given an initial and a final position, the SGP computes the geometric curve (considered safe) to which the robot should tend, exploiting the algorithm proposed in [1]. Taking into account that the static map used for the robot navigation could be not fully updated, the waypoints computed at the supervision level are integrated within the GP, which lets the robot follow the planned trajectory through a cost-based algorithm. The LP modifies online the path computed by the GP, when unexpected obstacles are detected.

The algorithm used for the SGP, based on artificial potential fields, has been written in MATLAB, while the GP and LP implementations exploit the ROS (Robot Operating System) Navigation Stack, which provides packages ready for localization, mapping, navigation and reference frames tracking. The output plan computed by the SGP has been packed and stored on the ROS Parameter Server through the MATLAB Robotics System Toolbox ™ [9].

The GP algorithm has been built based on the A* cost-based structure, assigning low costs to the desired points to be traversed, and thus forcing the robot to follow the set of waypoints computed by the SGP. The LP updates the GP in presence of unexpected obstacles, and exploits the `TrajectoryPlannerROS` wrapper, which adheres to the `nav_core::BaseLocalPlanner` interface.

B. Smart AMRs as meta-sensors

The proposed sensor system is thought for any flexible production line composed by AGVs, workstations and cobots, in which the workspace is shared with human operators, as specified in [3], [4]. The AMR collects the information from its surroundings, and when particular objects are detected, it advertises them to the other agents moving within the system. In our case, we consider the human operator as the target of interest.

In order to cover a wider range of measurements and avoid false positives for obstacle detection, we employed a sensor data fusion algorithm that merges the information coming from the IP camera and the laser range finder. The camera is used for the recognition of the objects, while the laser readings provide the distance measurements of the object with respect to the robot. We exploited the *You Only Look Once* (YOLO) [10] real-time object detection system, which classifies and labels the region of interest from the video frames. After that, we adopted an extrinsic calibration method based on [11], which maps the laser points in the camera coordinates and projects them in the image plane. In this way, it is possible to identify the human operators and measure the distance between the human and the robot.

When the human operator is within the field of view of the robot, the sensor system virtually encircles the location of the human within an area not accessible by the network of mobile robots, characterized by a greater safety radius value with respect to other obstacles.

III. Experimental results

The most relevant results experimentally obtained are summarized hereafter. More details about all the analyzed test cases can be found in [2], [3].

A. *Supervisory path planning: testing*

Figure 1 shows that at first the GP computes a path coherent with the one determined by the SGP, due to the absence of obstacles not already included in the static map. When an unexpected obstacle is detected instead, the LP avoids it by re-planning the path, trying, when possible, to go back to the desired safe curve. The complete video of the test is available in [12].

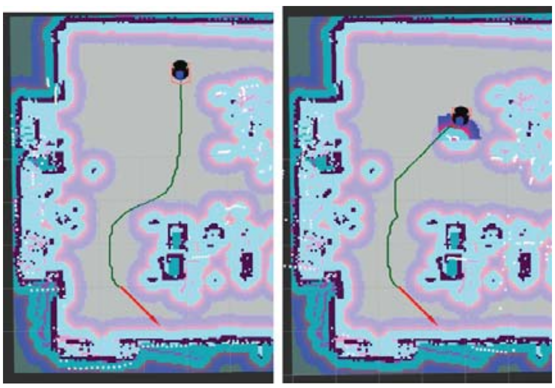

Fig. 1. rviz view during the considered test case execution. The left figure reports the plan before the obstacle appears, while the right one shows the re-planning action.

B. *Smart AMRs as meta-sensors: testing*

In Figure 2 we can see that the algorithm is able to identify several human operators and hence publish them as virtual obstacles leading to a more conservative and consequently safe behavior. The video of the test is available in [13].

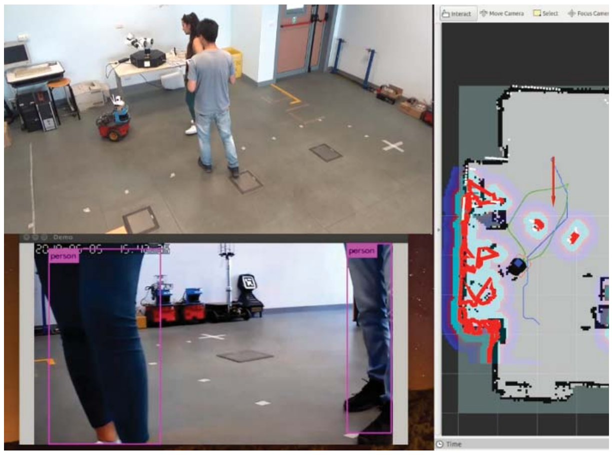

Fig. 2. This screenshot shows that several human obstacles can be simultaneously detected.

IV. Conclusions

The results reported in this document can be seen as the basic elements of a future wider anthropocentric industrial paradigm: since the SGP planning algorithm switches its behavior to a more standard A* path search (ensuring the shortest path and including obstacle avoidance) when significantly far away from the safe path, a safe behavior is ensured in this case as well, but guaranteeing at the same time an overall efficient behavior that avoids the generation of too long paths for the goal completion. When imposing the passage on a path considered as safe (i.e., natively dedicated to the mobile robots only), we do not stray too much from the traditional AGV behavior, but the awareness of the AGV about its surroundings is provided by the AMR meta-sensors net, which enables the AGV to move in a more conservative and safer way, when human operators are present.

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