Integrated Obstacle Avoidance and Path Following Through a Feedback Control Law

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Abstract The article proposes a novel approach to path following in the presence of obstacles with unique characteristics. First, the approach proposes an integrated method for obstacle avoidance and path following based on a single feedback control law, which produces commands to actuators directly executable by a robot with unicycle kinematics. Second, the approach offers a new solution to the well-known dilemma that one has to face when dealing with multiple sensor readings, i.e., whether it is better, to summarize a huge amount of sensor data, to consider only the closest sensor reading, to consider all sensor readings separately to compute the resulting force vector, or to build a local map. The approach requires very little memory and computational resources, thus being implementable even on simpler robots moving in unknown environments.

Keywords Obstacle avoidance · Mobile robots · Path following

1 Introduction

The article proposes a new approach to obstacle avoidance in real world environments. Researchers in mobile robotics experiment on a daily basis that obstacle avoidance plays a fundamental role for two reasons. First, it is very likely to happen that a robot which has planned a path a priori is required to deviate from the nominal path due to the presence of unforeseen obstacles. Second, even if the environment is completely known and no additional obstacles are encountered, the robot has only an approximate estimate of its own position, since self-localization is necessarily affected by errors. Then, as a consequence of localization errors, the robot needs to be able to deal with an environment which—in a subjective view—is not exactly as expected, thus requiring strategies to properly modify the nominal path.

In the literature, many approaches have been proposed to provide the robot with obstacle avoidance capabilities. However, with a few exceptions, almost all of them suffer of two drawbacks.

First, in traditional approaches, obstacle avoidance is simply defined as the problem of reaching a goal configuration in the presence of obstacles (e.g., [1, 5, 14, 21]), without guaranteeing a predictable and measurable path following behaviour (these latter issues are mostly investigated in the absence of obstacles: e.g., [9, 35, 38]). Specifically,
the directions to follow in order to avoid obstacles are usually computed in a separate phase with respect to motion control, usually by assuming a point—like robot. Then, once a velocity vector avoiding obstacles has been computed, it is necessary to properly compute a control law which enables the robot to move in the proper direction, which is not a trivial task by itself and—due to constraints on the vehicle kinematics—in some case can be not feasible at all.

Second, even if more recent approaches consider obstacle avoidance and motion control in an integrated perspective (e.g., [6, 12, 30, 34]), a major problem concerns how obstacles detected by a proximity sensor (e.g., a laser scanner) should internally be represented for the purpose of obstacle avoidance. In fact, both in the case that raw sensor data are reactively used to compute a candidate direction of motion, and in the case they are merged in a certainty grid or a similar map-like representation, obstacles are perceived as a cloud of points. That is, the notion of obstacles as individual entities is absent in raw sensor data: if this additional information is required for obstacle avoidance, it can be obtained only through a clustering procedure which requires additional computations and is prone to classification errors.

The approach proposed in this article gives an answer to these two problems. Specifically, it proposes a simple feedback control law which, on the basis of the robot’s position and raw sensor readings, deforms the nominal path in order to deal with unforeseen obstacles, and generates control inputs which guarantee asymptotic convergence to that path by taking into account kinematics constraints. The system relies on a path following approach which has been described in [25], and is adapted here to include real-time obstacle avoidance capabilities.

Section 2 discusses other approaches in the literature. Section 3 describes the system, by presenting the basic control law for path following, and then showing how it is adapted to consider sensor readings returned by a proximity sensor. Section 4 describes experiments performed with a real-robot equipped with a laser scanner. Conclusions follow.

2 Related Work

The article considers a robot moving in a partially known environment, e.g., for autonomous transportation [22, 32] or surveillance [8, 10]. In these application domains, a planner is usually available which produces a sequence of waypoints (the problem of planning a path to the final destination is not faced here, see however [33]). Then, since a path connecting each waypoint to the next one can be easily computed, the robot has not to deal with such a problem as finding the way out of a maze, but rather on following the path which has been planned a priori as more accurately as possible.

If, as it often happens, the robot can be modelled as a unicycle, path following reduces to the problem of controlling the steering velocity (with a given linear velocity) in order to follow the assigned path. The problem has been deeply investigated in literature. Earlier approaches [38] compute a normal projection of the robot onto the path, and control the steering velocity in order to asymptotically regulate to zero the distance from such projection. Unfortunately, depending on the path’s curvature, this class of approaches puts heavy constraints on the maximum initial distance that the robot can have from the path. This problem has been solved by more recent approaches [9, 35], which assume a virtual target moving on the path with a prescribed law of motion instead of computing the normal projection, and aim at minimizing the distance from the moving target. Also this second class of approaches has drawbacks: for instance, they require the explicit computation of the progression rate of the moving virtual target that is governed by an additional differential equation, thus making implementation more complex. Additionally, the work described in [9] does not guarantee asymptotic convergence to the path during path following.

Obviously, it can happen that the prescribed path cannot be followed due to objects left unattended, pieces of furniture, other vehicles, or people. Under these conditions, the approach used by commercial Automated Guided Vehicles (AGV) to avoid obstacles in real—world situations (e.g., in a corridor crowded with people) is often not to