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Driving With Single Deformable Polyline Tentacle and Velocity Obstacles

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Abstract

Intelligent transportation systems are emerging as the approach to dramatically improve efficiency while at the same time leading to the goal of zero accidents. Autonomous driving is now possible but still greatly limited to low speed driving. This is mainly due to computational load in detecting the road and objects, path planning and limited controller cycles. The focus of this work is to develop faster trajectory planning scheme given the sensed environment map (occupancy grid). This work utilizes interaction of single projected trajectory from the non-holonomic vehicle kinematic model with the objects in the road. Furthermore, the planned trajectory is made sensitive to car speed. Simulation results with non-linear vehicle kinematic model shows that the proposed combination of single trajectory and velocity objects gives faster satisfactory trajectory with safe obstacle avoidance while following prescribed way points.

Key words: Deformable poly-line tentacle, Velocity objects, trajectory planning and non-holonomic constraints.

1. Introduction

In recent years, the field of intelligent vehicles has been rapidly growing worldwide both in the diversity of applications and in increasing interest in the passenger cars, trucks, public transport and military sector. These systems offer the potential for significant enhancements in safety and operational efficiency. As one component of intelligent transportation system (ITS), intelligent vehicles use sensing and intelligent algorithms to understand the environment immediately around the vehicle, either assisting the driver in vehicle operation (driver assistance) or fully controlling the vehicle (automation). The DARPA grand challenge [1] and the goggle driverless car [2] are the most notably recent examples of autonomous driving. Driver assistance systems have a variety of representation in broad categories as collision warning systems, collision avoidance systems, cruise control systems, driver monitoring systems, etc. These systems may provide warning for eminent hazardous situation or may take active control to avert eminent accident. Such a system is built with the capability of sensing the driving environment and an acting control system that interprets the sensed information to identify appropriate action to the situation. The action may be warning to the driver or active control by steering or slowing the car or altogether stopping the car.

Furthermore, this system in societal context could reduce accident cases due to the systems increased reliability and interestingly would remove constraints on occupant’s state. It would not matter if the driver is too young, too old or if other frame of mind are not suitable to drive. Because the system would not allow the car to crash.

2. Problem statement

Three of the challenges facing autonomous driving systems are; detecting the road and obstacles in time, timely path planning or trajectory planning and finally driving as fast as the trajectory planned allows. The existing systems are greatly limited in application due to processing time overheads. In the DARPA grand challenge autonomous vehicles could operate up to 36Km\h, the Goggle car operates up to a maximum of 40km\h and the robotics applications are even much slower. The normal car speed are far above these ranges. The processing speed is heavily influenced by the perception model and perception-control interfacing for control evaluation.

While sensing capabilities and faster controllers are being developed in other efforts, the focus of this work is to develop faster trajectory planning scheme given the sensed environment map. The main objective in our autonomous system is to drive and not to explore in contrast to SLAM approach. ie just demand safe driving within the environment.

3. Related works

The oldest approach to autonomous navigation is the SLAM. Simultaneous localization and mapping (SLAM) is the process of continuously estimating the position and orientation of a robot in a previously unknown environment. This is achieved by incrementally building a map of the environment from the available sensor data, which, at the same time, is used to re-estimate the position of the robot in regular intervals [3], [4].one of the first robots,Shakey [5], used cat-whiskers (microswitches actuated by a 6-in.long coil spring extended by piano wires to provide longer reach) to sense the presence of a solid object within the braking distance of the vehicle when traveling at top speed [see Figure 2(b)].In his cybernetic thought games Braitenberg [6] showed that complicated behaviour can emerge by very simple mechanisms, and almost all of his vehicles (known under the term Braitenberg vehicles) use sensors resembling an insects antennae [Figure (2c)].

Some systems in mobile robotics integrate modules in which some sort of precalculated trajectories are verified to be drivable: Kelly and Stentz [7] follow the idea of model referenced control, Landau[8] implemented through command space sampling and evaluating a set of candidate trajectories. In (Lamon, Kolskin) [9] a set of feasible arcs was used as a first step in in path planning algorithm.

Stanley, the robot that won the DARPA Grand Challenge in 2005, used a set of candidate paths (nudges and swerves) for path planning [1].

In the DAMN (Distributed Architecture for Mobile Navigation) framework [10], four different arbitration schemes for integrating the results of different distributed behaviours are proposed. One of those arbitration schemes is actuation arbitration, in which different turn behaviours cast votes on candidate vehicle curvature commands.

In the work of Hundelshausen et al [11]. basic approach using a set of virtual antennae they call ’tentacles’ probing an ego-centered occupancy grid for drivability candidate commands. The candidate commands are not only used as candidate instances in a command space but the tentacles are also used as perceptual primitives, used to evaluate an occupancy grid. This evaluation process includes some new structures and aspects, including the differentiation between a support and a classification area, the use of a longitudinal histogram for classifying tentacles as being drivable or not, determining the distance to the first obstacle along a tentacle, and a speed-dependent evaluation length (the crash distance) that permits reduction of the number of required primitives drastically.

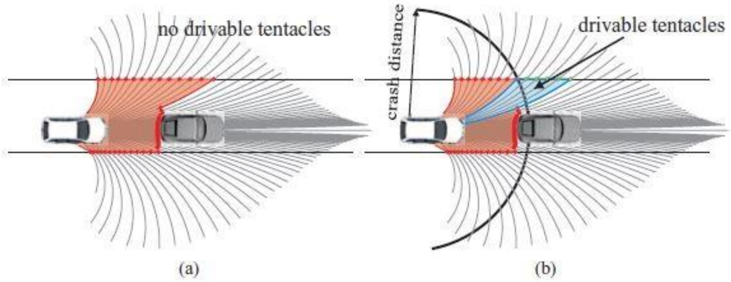


Fig. 1: The case in which a car is blocking the right lane of a road and only a narrow passage is left to pass the car. The red points mark the locations along the tentacles where the vehicle would hit either the car or the road border. As can be seen, no tentacle is free of obstacles. Hence, by neglecting the distance to an obstacle, all tentacles would be classified undrivable (a). In contrast, panel b shows the concept of classifying tentacles as undrivable only in case of being occupied within a speed-dependent crash distance (see main text). In this case, some drivable tentacles remain, allowing a pass of the car.

Another work in the context of planetary rover exploration that looks very similar to ’Driving with tentacles’ is GESTALT (Grid-based Estimation of Surface Traversability Applied to Local Terrain) [12]. GESTALT selects an arc with maximum goodness according to various criteria; however, the main difference with ’Driving with tentacles’ is that GESTALT uses a global grid and accumulates data over time in this grid. In doing so, the approach becomes an instance of the SLAM problem

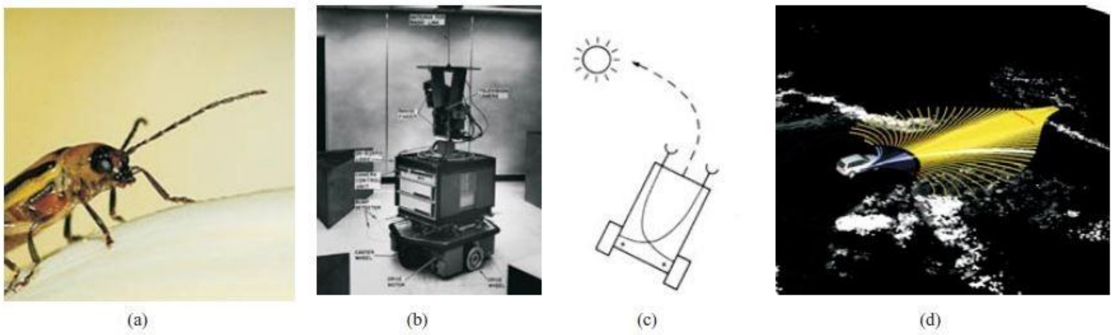


Fig. 2: (a) among other functions, insects use antennae as tactile sense. (b) Shakey (Nilsson, 1984)one of the first robots uses mechanical cat-whiskers to detect collisions. (c) Braitenberg vehicles use some sort of antennae with simple, hard-wired reactive mechanisms to produce complex behaviours. (d) Approach using speed-dependent sets of antennae that called tentacles.

Another similar work by (Coombs et al.)[13] a fixed tree structure with five levels(the root being located at the Robot’s position) is used . The first level consists of 20-m-long precalculated clothoids and the other levels consists of straight line connections. Within this tree, all possible paths from the root to the leaves form the set of possible trajectories. The whole tree consists of about 4000 edge, resulting in a combinatorial power of more than 15million trajectories.

Benenson and parent [14], formulated control synthesis (Planning scheme) as a search problem in the command space. They searched the plan p that will move the vehicle along the defined route. The search for the best trajectory is executed periodically. To guide the exploration in the sequence of commands space they use a hybrid between greedy search and RRT [15] method mixing directed search with random search.

The use of multiple antennae or clothoids is computationally intensive thus takes considerable time for path planning. This is a great impediment to real time high speed application. In this work we address computational latencies arising in path planning. Single tentacle trajectory provide a reliable and direct method for representing the vehicles path for the next few seconds of driving. Secondly, our approach is to grow obstacles rather than the vehicle path width for safe clearance between the car and other obstacles. Growing the object is less computationally expensive than growing the width of the vehicle path. Lastly, nonholonomic constraints are considered use of velocity objects maintaining appropriate lateral and longitudinal clearance to obstacles sensitive to the vehicle’s speed.

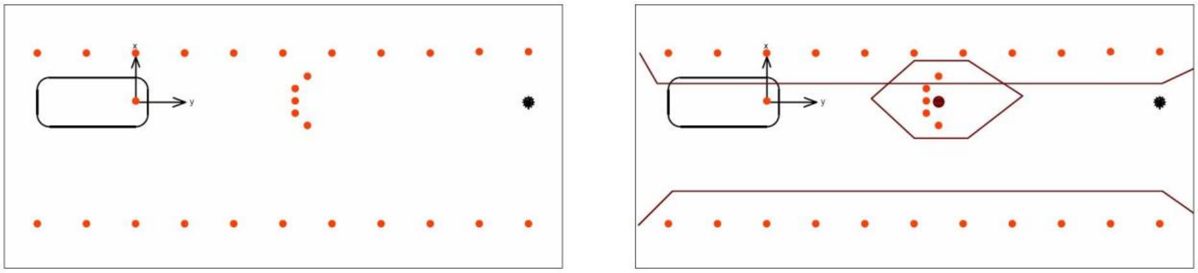
4. Methodology

We propose a virtual driving framework where a virtual vehicle (Kinematic model) drives in a virtual map (occupancy grid). The physical vehicle is coupled to the virtual model through vehicle odometry such that the physical vehicle follows accurately the motions of the virtual model. The occupancy grid presents the vehicle’s global coordinates, vehicle waypoints (intended path) and other objects from the car’s exteroceptive sensors (vision).

The objective is to keep the vehicle directed to the next way point and at the same time avoid obstacles along the way. The process starts with the inverse kinematic model to generate vehicle inputs that will direct the vehicle to the next way point. The inputs derived are used to generate a projected trajectory to that next way point. This projected trajectory interacts with the obstacles in the proximity which are represented by expandable poly-line boundaries sensitive to vehicle’s velocity (velocity objects).

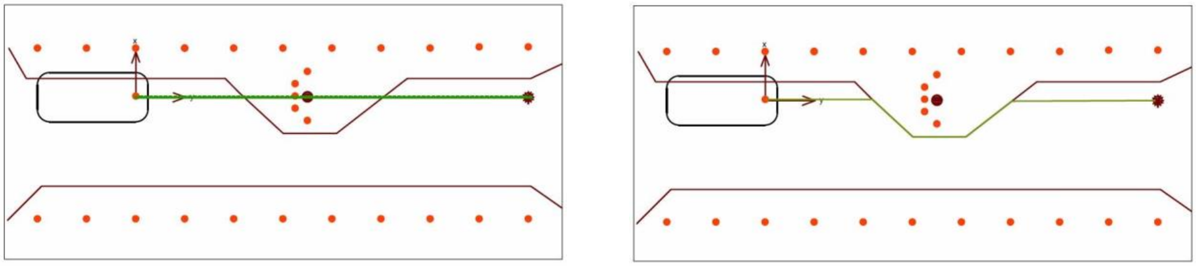
The velocity objects deflects the projected trajectory appropriately to safe zones providing more clearance for collision avoidance. The velocity objects are obtained through dynamic affine transformations. An active control strategy formulated as a trajectory tracking control problem the takes the effect of tracking the deformed trajectory.

This constitutes the scheme of driving with single deformable tentacle opposed to use of clothoids in which several trajectories are evaluated thus demanding more computational time.



(a) Developed metric map

(b) Objects fenced with polylines



(c) Objects merged to reduced polylines and single vehicle trajectory to the next waypoint

(d) Vehicle trajectory deformed to safe zones

Fig. 3: Path planning with single polyline and velocity objects

5. Results

Simulations of this new approach is done using Matlab. The simulations illustrate the vehicle's intended trajectory, its interaction with obstacles and obstacles boundary growing sensitive to car speed.

The figures are in pairs with the upper figure showing the desired path and the lower figure showing the navigable path to the desired destination. Figure 4 shows a case of low speed driving with atypical driving speed of 20Kph. The compensated object size is smaller than other cases and path evades the object on its safe boundary. Figure 5, 6 and 7 shows case for higher speeds with increasing speed respectively. The compensation for speed is clearly observable and the path safely evades the objects.

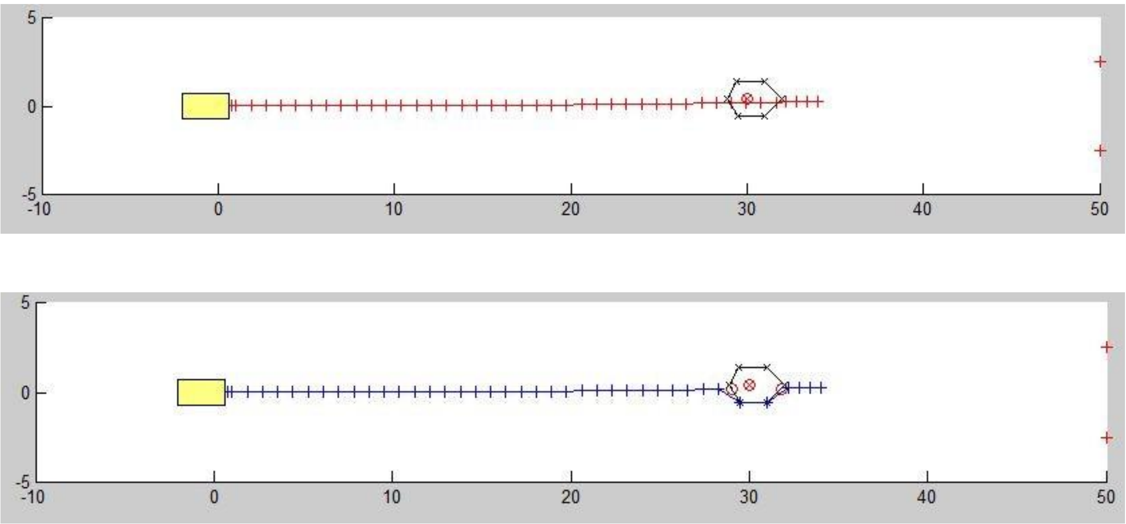


Fig. 4: Driving at 20kph

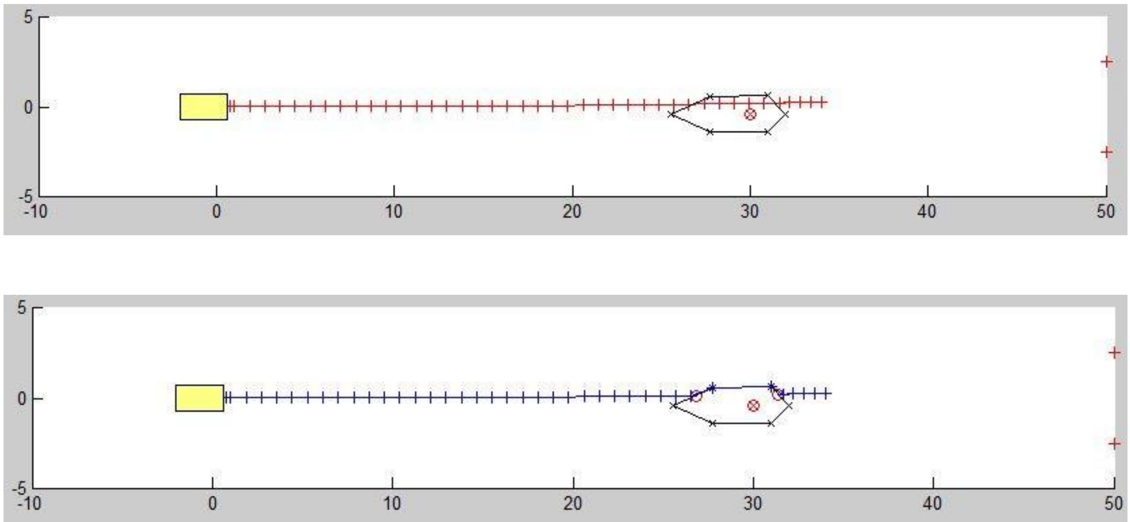


Fig. 5: Driving at 80kph

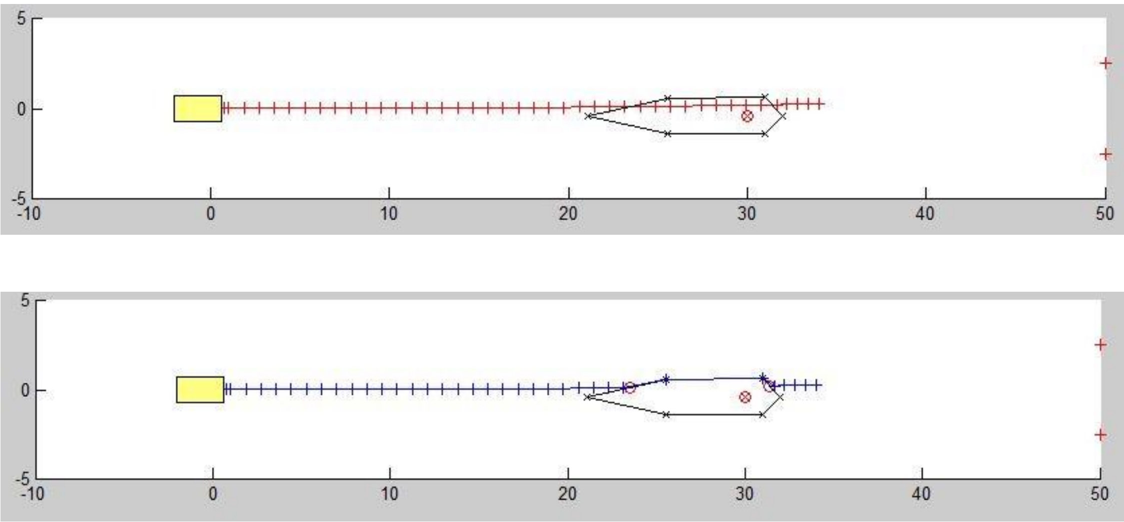


Fig. 6: Driving at 160kph

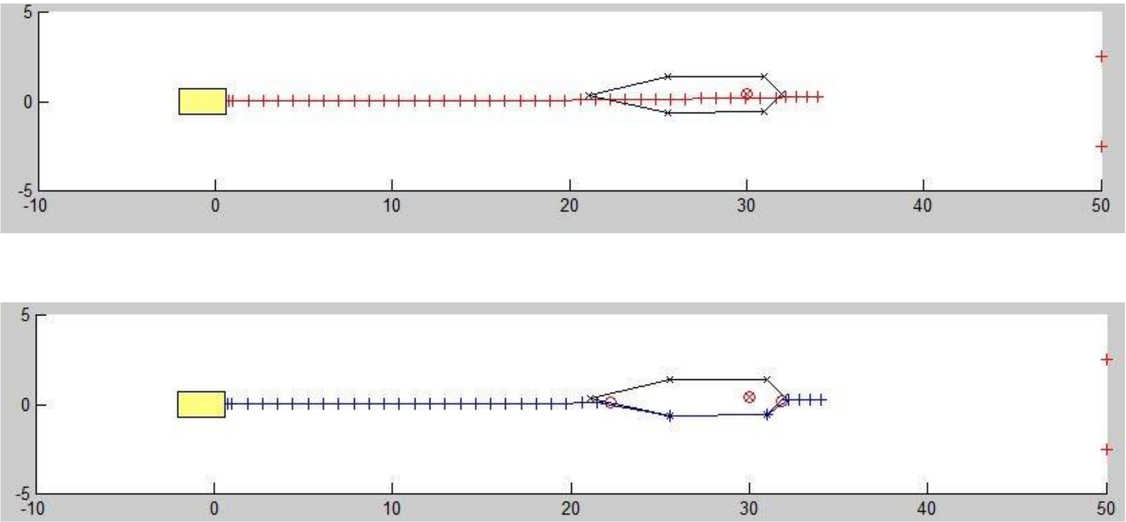


Fig. 7: Driving at 160kph

6. Discussion and conclusion

We demonstrate that this algorithm has an important notion of completeness in the sense that it can support both autonomous driving and driver assistance system. Simulation results on non-linear vehicle model show that the proposed combination of single tentacle and velocity object gives satisfactory trajectory with safe obstacle avoidance employing either path tracking or trajectory tracking by non-holonomic vehicles.

In this work, safe trajectory is generated using the interaction of single tentacle and velocity objects in which the simplified dynamics of the vehicle are used to predict the state of the vehicle over the look-ahead horizon. The deformable tentacle provides both reactive and deliberative collision avoidance which combines continual replanning and tracking in combination with dynamic windows. This provides a representation which easily supports use of locally optimal linear feedback control policies to track planned trajectories computed by the deformable single tentacle.

Another benefit of this approach is that the vehicle inputs changes continuously without jumps since the deflections in the projected vehicle trajectory normally detected quite a head in the vehicle's trajectory allowing smooth tracking. This positively considers the nonholonomic constraints of a vehicle. Unlike in the clothoid approach the evaluated trajectory are discontinuous, thus will exhibit jumps and jerky driving which compromises on ride comfort.

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