CHAPTER XII. PATH EDITING

XII.A. Discussion

Many teams which participated in the 2004 QID or GCE or 2005 GCE reported path editing was in use by the team. “Path editing” is defined herein as manually or algorithmically increasing waypoint density of the path defined by the 2004 QID or GCE or 2005 GCE RDDF.

XII.B. Analysis

Several teams which participated in the 2004 QID or GCE or 2005 GCE reported path editing was in use by the team. For example:

- Team 2004-03

Team 2004-03 stated: “The only two databases that the vehicle will have pre-stored are the provided waypoint (RDDF) and our augmented waypoint set (ARDDF). The ARDDF will be generated using a custom application that allows pre-race offline processing of satellite imagery to increase the density of waypoints to provide a tighter route for the vehicle to follow.” ([92], p. 4).

- Teams 2004-13 and 2004-14

Teams 2004-13 and 2004-14 stated: “Using the DARPA supplied waypoint list distributed two hours prior to the start of the race, we will analyze the route... The result of this analysis will contain micro-waypoints (additional waypoints between DARPA-provided waypoints)...” ([232], pp. 2 - 3) and ([132], p. 3).

- Team 2004-18

Team 2004-18 stated: “Reactive Route Planning will be accomplished dynamically from all available localization and obstacle data by placing intermediate waypoints between DARPA defined route waypoints that the Challenge vehicle must also pass through.” ([48], p. 3).

- Team 2004-25

Team 2004-25 stated: “In the two hours prior to the race, we will develop an optimal global path for the entire route. This will create a curved path within the course boundaries.” ([49], p. 8).

- Team 2005-04

Team 2005-04 stated: “Before the race, when the waypoint file is supplied, we have developed software to... Add virtual waypoints... Shift location of waypoints (presumably within the given boundaries)...” ([169], p. 7).

- Team 2005-10

Team 2005-10 stated: “Virtual waypoints are computed on-the-fly to supplement the DARPA waypoints. Waypoints in curves are fitted to a spline to better define the course.” ([176], p. 2) and “The path planning algorithm attempts to maintain the vehicle’s front differential directly above the proper path at all times... This algorithm computes 'virtual waypoints' between the DARPA supplied waypoints. On long straight portions of road, it adds these virtual waypoints for local guidance when the DARPA waypoint may be over a mile away. In curves, the algorithm fits a spline to the given waypoints and adds additional virtual waypoints to smooth the path.” ([176], p. 5).

- Teams 2005-13 and 2005-14

Teams 2005-13 and 2005-14 reported algorithmically increasing waypoint density in the context of collision avoidance: “Collision avoidance modifies the preplanned route to swerve around a sensed obstacle represented as terrain with very high cost. The path planner generates the swerve maneuver by modifying the location of 1 meter spaced Waypoints.” ([11], p. 12 and [12], p. 12). However, Teams 2005-13 and 2005-14 later stated: “Path editing is a process that transforms a set of coarse waypoints and speed limits into a preplanned path with 1 m spaced waypoints.” ([24], p. 492).

- Team 2005-15

Team 2005-15 stated: “The very first step after obtaining the DARPA RDDF file is to improve the given route based on existing map data. Such data exists in the form of published maps and has been acquired by predriving certain roads prior to the course area being placed off limits. For the Grand Challenge Event, during the two hours between obtaining the RDDF file and the actual vehicle start, a reference path is computed which includes the DARPA waypoints, but also creates a more refined path at a higher resolution. This reference path is the basis for the vehicle following the given route.” ([53], pp. 8 - 9).

- Team 2005-16

Team 2005-16 stated: “To attain a suitable trajectory and associated maximum velocity, the RDDF file is processed by a smoother. The smoother adds additional via points [*sic*] and ensures that the resulting trajectory possesses relatively smooth curvature. The preprocessing then also generates velocities so that while executing a turn, the robot never exceeds a velocity that might jeopardize the vehicle’s ability to avoid sudden obstacles. This calculation is based on a physical model of the actual vehicle." ([195], p. 10).

- Team 2005-20

Team 2005-20 stated: "The real time computer does the fundamental global position point following with a 'best estimated path (BEP)' that is calculated beforehand using HANSEL. This program currently interpolates between the large GPS increments provided in the RDDF file. This algorithm's purpose is to generate points at increments that the GPS follower could follow even without a path planner active." ([56], p. 6).

XII.C. Results

DARPA increased waypoint density for the 2005 GCE, defined forced deceleration lanes, and eliminated course segments in excess of 305 m (1000 ft). See paragraph II.D. With the exception of introducing deceleration lanes which forced challenge vehicles to decelerate to significantly lower speeds before a significant change in bearing or other terrain features, the author was unable to determine why DARPA increased waypoint density and eliminated course segments in excess of 305 m (1000 ft) if team strategies to manually or algorithmically increase waypoint density were in common use. For example, each waypoint defined by the 2004 or 2005 GCE RDDF was not accompanied by a change in allowed speed limit and waypoints did not represent a "route" in the traditional sense to a human driver, i.e.: "Go one block, turn left, then go two blocks, and turn right. The shopping center is on the right."

XII.D. Conclusions

At least one team successfully completed the 2005 GCE by smoothing the path without increasing waypoint density: Team 2005-06.

Team 2005-06 stated: "The path planning systems are responsible for ensuring that any path they generate is drivable by the vehicle. To accomplish this, the path planning systems use cubic b-splines to interpolate a path between waypoints. These smoothed paths allow the vehicle to make much more accurate sharp turns. In testing, [Team 2005-06] has successfully navigated several 180 degree hairpin turns with extremely low radii." ([172], p. 10). Team 2005-06 later stated: "The rules did not prevent normalization of DARPA's data before they were fed to the vehicles, neither did they prevent elevation map databases, however, [the challenge vehicle] did not make use of any information other than its sensor readings and DARPA's waypoint data given to it in raw form." ([28], p. 510).

A similar strategy was in use by several other teams which did not report path editing was in use by the team and which did not successfully complete the 2005 GCE, for example: Teams 2005-08, 2005-18, and 2005-19. As a result, the author concluded it was possible to successfully complete the 2005 GCE without increasing waypoint density, and that path editing was not a key factor, but that insufficient technical detail was available to conclude path editing was a negative selector.

The strategy employed by the author to limit the speed of a vehicle in simulation is based on the maximum velocity allowed by vehicle and course geometry, which was determined by analysis of the 2004 and 2005 RDDF, and is not dependent on increased waypoint density. Review of published records revealed this approach was simplistic: although it results in a smooth path from one waypoint to the next, it does not take into account factors such as surface condition, the effect of slope, or the need to alter heading to avoid an obstacle.

However, review of the maximum allowed turn radius calculated by the RDDF analysis application using the 2005 GCE RDDF (see Chapter III.) revealed:

- There was no rollover risk to challenge vehicles during the 2005 GCE. The minimum safety factor in the 2005 GCE course design was 9.8. See paragraph III.D.1.d. A challenge vehicle would have been able to complete the 2005 GCE in 9.45 hours at a maximum course-wide speed limit of 15 mph. See paragraph II.C.7.b. A challenge vehicle would have been able to complete the 2005 GCE in 6.81 hours at a maximum course-wide speed limit of 25 mph, in less time than Team 2005-16. See Table XIII. There was significantly decreased risk of side slip due to surface condition at a reduced speed of 15 or 25 mph in a turn with a safety factor of 9.8.

- No additional waypoints defined by the 2005 RDDF were identified at which the effect of slope would have resulted in a challenge vehicle being at risk of rollover on a slope of five, ten, 20, or 30 degrees. See paragraph III.D.1.a.

In addition, DARPA did not place obstacles along the 2005 GCE course to test challenge vehicle obstacle avoidance capabilities. See Chapter I.

As a result, although the author's approach was simplistic, the author considers it more than adequate for conditions encountered during the 2005 GCE, and asserts this provides some insight into the success of Team 2005-06's path planning strategy.