CHAPTER X. OVERALL CONCLUSIONS

In an attempt to determine what problems, exactly, were solved during the Grand Challenge, the author identified key factors. Several key factors which could have been evaluated through the use of simulation prior to the Grand Challenge were identified as potential simulation targets. Although installation and use of Player and Gazebo presented challenges, the author successfully evaluated three simulation targets using Player and Gazebo.

Overall, the author concluded the use of simulation would have enabled teams to effectively visualize the interaction of their challenge vehicles with the environment, and quickly and easily prototype and evaluate ideas such as the oscillating sensor mount in use by Team 2005-06.

During the evaluation of LIDAR configuration, the use of XML configuration files by Player and Gazebo to configure the simulation greatly increased flexibility and ease-of-use. The author was able to modify the simulation configuration quickly between trials by changing one or two lines in a text file.

In addition, the use of simulation made the results *reproducible*, with a high degree of fidelity. As a result, the author concluded attempted solutions to problems encountered during this research could be confirmed to be effective in simulation by eliminating variability in initial conditions.

The four teams that successfully completed the 2005 GCE completed the course in 06:53:58 hours (Team 2005-16), 07:04:50 hours (Team 2005-14), 07:14:00 hours (Team 2005-13), and 07:30:16 hours (Team 2005-06), although Teams 2005-13 and

2005-14 adopted a "dual speed" strategy and estimated completion of the 2005 GCE in 06:19:00 and 07:01:00 hours, respectively.

Teams 2005-13 and 2005-14 later stated ([21, p. 500]):

> While the strategy was successful in that both robots completed the challenge, it limited [the challenge vehicle] below its ability and, in retrospect, prevented it from winning the Grand Challenge.

Team 2005-13 did not complete the course in the projected time because of undiagnosed engine problems ([21, p. 502]).

The author implemented an improved steering controller that limited the velocity of the vehicle to the maximum allowed by vehicle and course geometry and was able to demonstrate that a model using this controller would not be subject to rollover in 2004 GCE course segment 2570-2571-2572. The representative challenge vehicle and many other challenge vehicles would have been at risk of rollover if entering 2004 GCE course segment 2570-2571-2572 at the maximum velocity allowed by the 2004 GCE RDDF.

This was similar in concept to the method Team 2005-16 reported was in use by the team during the 2005 GCE, and which the author considers a key distinguishing factor. Team 2005-16 stated ([49], p. 10):

> ...[the challenge vehicle] always assumes an allowable velocity according to pre-processed RDDF file, and it slows down in curves so as to retain the ability to avoid unexpected obstacles. The vehicle also adapts its velocity to the roughness of terrain, and to the

nearness of obstacles. The specific transfer function emulates human driving characteristics, and is learned from data gathered through human driving.

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.

However, the author concluded that by eliminating the risk of rollover, it was possible for teams to complete the 2004 GCE course at the maximum speed allowed by the RDDF, with the sole exception of 2004 GCE course segment 2570-2571-2572, in less time than Team 2005-16 completed the 2005 GCE (6.90 hr), *with no pre-planning or pre-mapping required*.

DARPA stated ([50]):

Course speeds that are between 26mph and 50 mph (inclusive) are advisory and are provided for guidance purposes.

As a result, the author concluded, due to the safety factor inherent in the design of the 2004 and 2005 GCE courses, it would have been possible for a challenge vehicle to have completed the course in less time than the ideal time by traveling at speeds higher than the “advisory” speed limits allowed by the RDDF at no additional risk of rollover to the vehicle.

Although the teams could not have known this before receiving the 2004 GCE RDDF, they could have performed the analysis documented by the Technical Report based on a model of their challenge vehicle dynamics. The author asserts this may have altered the pre-mapping or path editing strategies in use, and might have provided a competitive basis for the 2004 GCE similar to that of the 2005 GCE.