

Chapter 5

Conclusion

5.1 Conclusion

This study intended to apply optimization method to vehicle dynamics specifically to generate two optimal paths; one that would minimize travel time, and another that would maximize tire forces. The parametric study, shown in Chapter 4, demonstrates the effectiveness of the optimization algorithm. Therefore it can be concluded that optimal paths can be generated using optimization routine, such as the unconstrained optimization algorithm of Matlab, *fmins*. With further development, to improve computation time and accuracy, this idea can be effectively applied to practical cases such as an automated track testing procedure.

5.2 Practical Use

One of the most important aspects of a computational study is its practical usefulness. In other words, how the study can be used by other engineers and researchers. This study can be helpful in many ways. First and foremost, it can be used as a basis for future studies of optimization concepts applied to vehicle dynamics. This study may be referenced to show that optimal paths can be generated by setting up the constrained optimization problem using the unconstrained optimization algorithm of Matlab, *fmins*.

Further, this research can be used as a preliminary study for the development of a new tire testing procedure. An accelerated tire wear test path can be generated using the tire force maximization optimization routine. Often time, tire manufacturers want to compare the wearability of different tire constructions. By implementing this concept along with a feedback steering controller, an automated testing procedure can be developed to make tire wear testing more efficient and accurate. Test vehicles are subjected to automatically follow generated paths using the feedback steering controller, augmenting the ability of the test drivers. Further, automatic testing improves repeatability by consistently maintaining the same vehicle path while different sets of tires

are being tested. As such, simulation such as those presented in this study can be used as a tool to perform comparison tests on different vehicle specifications to determine the effects of changing a certain parameter on the optimal path of the vehicle.

5.3 Improvement on Overall Approach

There are two issues that can be improved upon for this research, computation time and optimal path prediction accuracy. It is difficult to improve upon both issues at the same time since they are interrelated. Using a faster processor to perform the optimization simulation, one can use higher degrees-of-freedom models or more accurate integration routines, to increase the prediction accuracy.

A more efficient search algorithm can also be used to make the convergence rate of the simulation faster. Genetics algorithm is a very attractive method to pursue. This method is relative new to the field of engineering. There have been a few studies on using this method in engineering applications [24]. The concept of genetics algorithm, however, is relatively difficult to understand and even more difficult to implement in the simulation algorithm. Since there has not been much development in this area, more time will be required to fine tune the algorithm and the verification of results.

Finally, a way to increase the speed of the simulation is to write the entire simulation program in C or C++ code. This entails efficiently writing loops, matrix operations, algebraic operations, input/output of files, and other mathematical manipulations in C or C++ [25]. Although this process can be time consuming if one is not proficient in C or C++, (such as the author). The return can be significant and would make the time investment worth while. By developing a custom simulation program in C or C++ , all the inefficient searches and look-ups that Matlab m-files or C or C++ compiled m-files perform can be eliminated, making the program only perform what is necessary to achieve the desired results.

5.4 Future Research

5.4.1 Using Optimal Control Methods

There are definitely opportunities for further study of optimal path generation. A different approach could be used to determine the optimal path, by using the optimal control theory. The Hamiltonian-Jacobi Bellman method could be used to solve for the closed-form solution. This method requires deriving the Hamiltonian equation of the dynamic system, determining the gradient of the Hamiltonian equation with respect to state variables to find the Lagrange multipliers, which are necessary when solving for the value of the objective function. Also the time history of the control variables can be found by determining the second partial derivative of the Hamiltonian equation with respect to control variables and set them equal to zero [26].

Another approach of solving the optimal control problem is to use dynamic programming approach to determine the optimal path. This method requires that the final states and conditions be defined. The problem is then solved backwards starting with the final position and then to the lowest cost optimal decision and so on. This process is repeated until the initial condition is found. The optimal control variables are the result of this procedure where each optimal decision was minimized.

5.4.2 Applying Optimal Path

Design a feedback steering controller that takes the path generated by this study or a similar study and tries to follow it. This is the other portion of the automated track testing idea mentioned in Chapter 1. The design of the feedback controller must be robust and should take into account the unmodeled dynamics such as the effects of the change in tire temperature and pressure, the effects of nonuniform friction coefficient of the road surface, and etc. Perhaps an adaptive controller would be ideal for this task.

5.4.3 Using Different Vehicle and Tire Models

A further study can be performed to determine the effects of different vehicle and tire models. For the vehicle model, other degrees of freedom could be included, rolling motion, pitching motion, and load transfer effects. As for the tire model, a more current

model can be used such as the Pacjeka tire model. This model requires using actual tire data and fitting it with a form of least square function. Lastly, include other vehicle dynamic controllers such as traction control and yaw control into the simulation to see the effects of these systems applied to determining an optimal path.

5.4.4 Parallel Processing Computation

To improve the computation speed of the optimization routine, a method such as the parallel processing computation can be used to evaluate the optimization algorithm. This method is consisted of using the UNIX platform workstation to run two processors to evaluate the algorithm. This, however, would require some modifications to the algorithm so that variable passing between processors is allowed. This method of computation will increase the speed of obtaining the optimal solution. Furthermore, with an increase in computation speed, more complicated vehicle and tire models can be used.