OPTIMAL VEHICLE CONTROL OF FOUR-WHEEL STEERING

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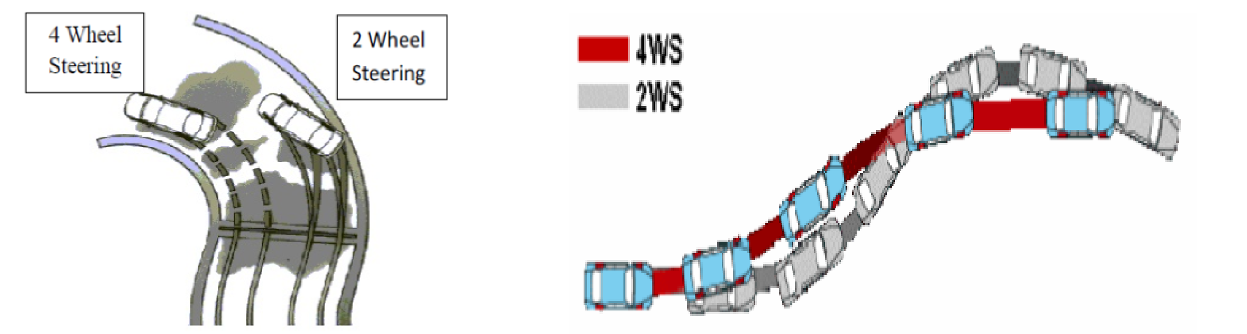
Background

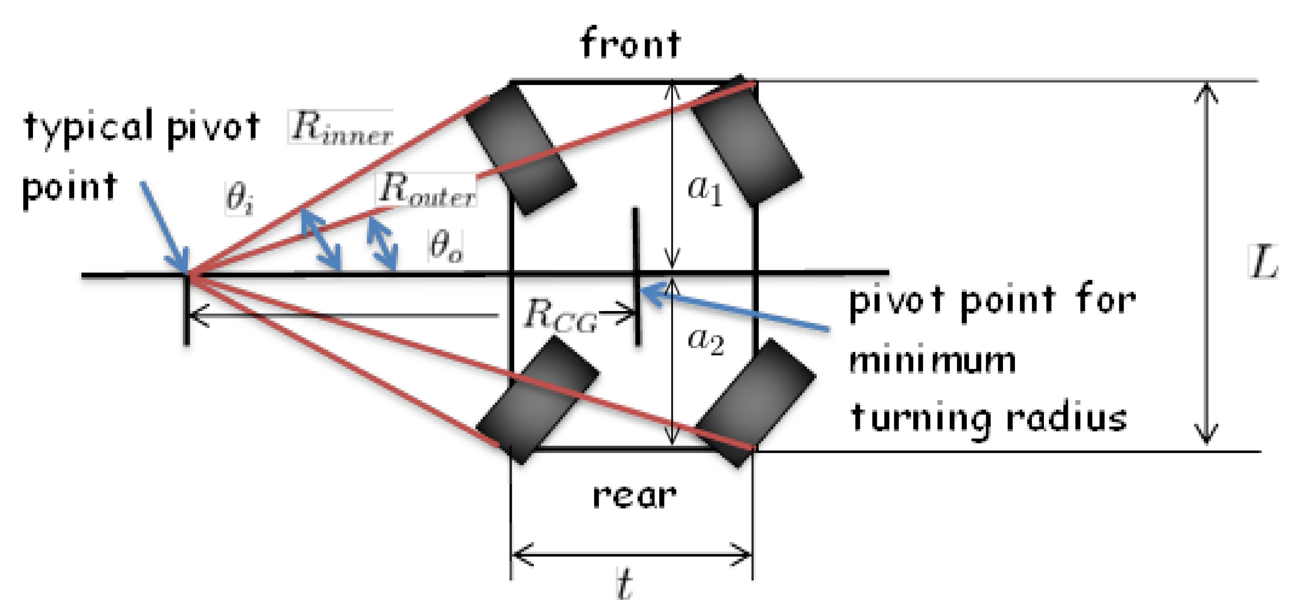
•Four-wheel steering (4WS) is an advanced control technique which can improve steering characteristics.
•Compared with traditional two-wheel steering (2WS), 4WS steers the front wheels and rear wheels individually when cornering (according to vehicle motion states: speed, yaw velocity and lateral acceleration).
•4WS can enhance the handling stability, improve the active safety for a vehicle, and allow a vehicle to turn in a significantly smaller turning radius.



Objectives

•Design a mechatronic control system to improve handling performance of the automotive vehicle under special steering circumstances and to reduce turning radius.
•Understand basics of vehicle dynamics, 4WS mechatronic control systems, steering kinematics, and Kalman filters.
•Find a function for vehicle trajectory while minimizing turning radius (trajectory based on car's center of mass).
•Parametrize trajectory curve with vehicle kinematics, steering geometry, desired steering angle, and turning radius.
•Design and test the Kalman filter performance by simulating a U-Turn maneuver to determine the state of a vehicle and how to control/optimize performance parameters.

Steering Geometry



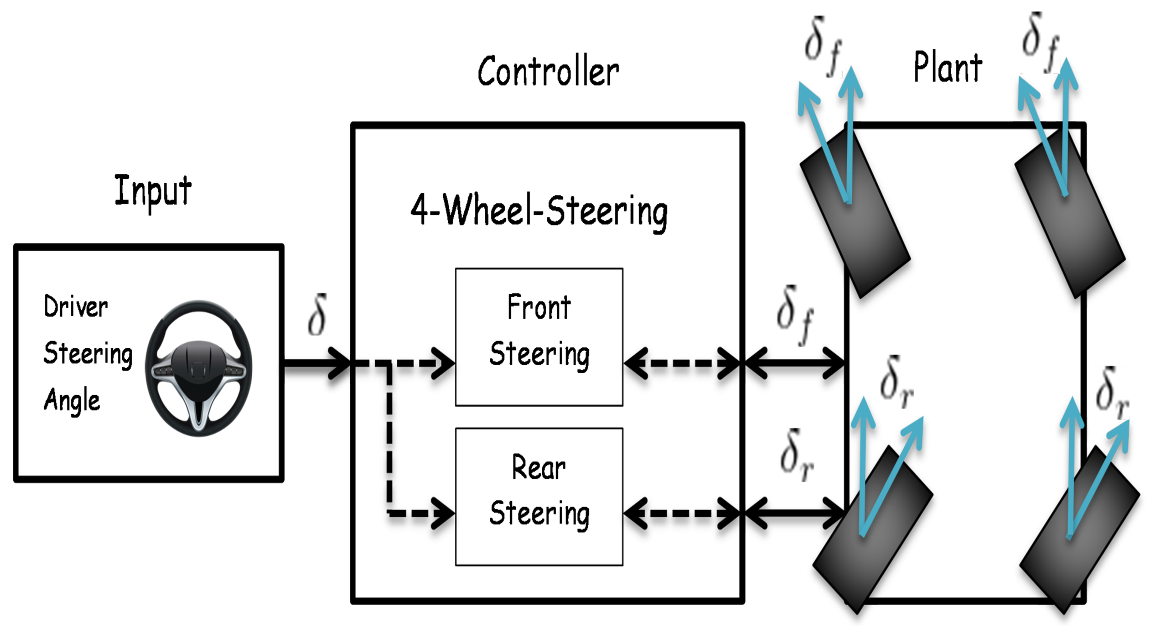
Derived Turning Radius Equation:

$$\text{turning radius} = R = a_2{}^2 + L^2\left(\frac{\cot\theta_i + \cot\theta_o}{2}\right)^2$$

Abstract

Automotive vehicles call for a range of steering activity: one extreme is highway driving with negligible turning. Another is steering during U-turn maneuvers, which calls for agile turning and a small turning radius to increase vehicle stability. System modeling and simulation are becoming widely used in autonomous vehicle engineering to reduce development time and improve the design and miniaturization of complex systems. This capstone project focuses on steering control system modeling, Kalman filter design, and simulation for optimal vehicle tracking. A 4WS control strategy is established using optimal control theory. The use of 4WS in a vehicle can reduce the turning radius in low-speed steering for more feasible maneuvering. In high-speed steering, 4WS can reduce the yaw rate and lateral movement of a vehicle.

4WS Mechatronic Control System Design



Steer-by-wire (SBW) four-wheel steered (4WS) conversion mechatronic controller

•System controls both the front and rear steering angles as a function of the driver input and vehicle dynamics.
•Offers greater maneuverability by moving turn center closer to center of vehicle.
•Half the turn radius of SWB 2WS vehicles for same alteration in wheel heading.
•When the rear wheels are steered in the opposite sense of the turning motion direction of the front wheels, the turning radius becomes less than when the rear wheels are not steered [1].

Vehicle Model

•Tracked vehicle is represented with simple point-mass model.
•Control inputs include: throttle position in range of -1 and 1 [unitless] and steering angle [degrees].

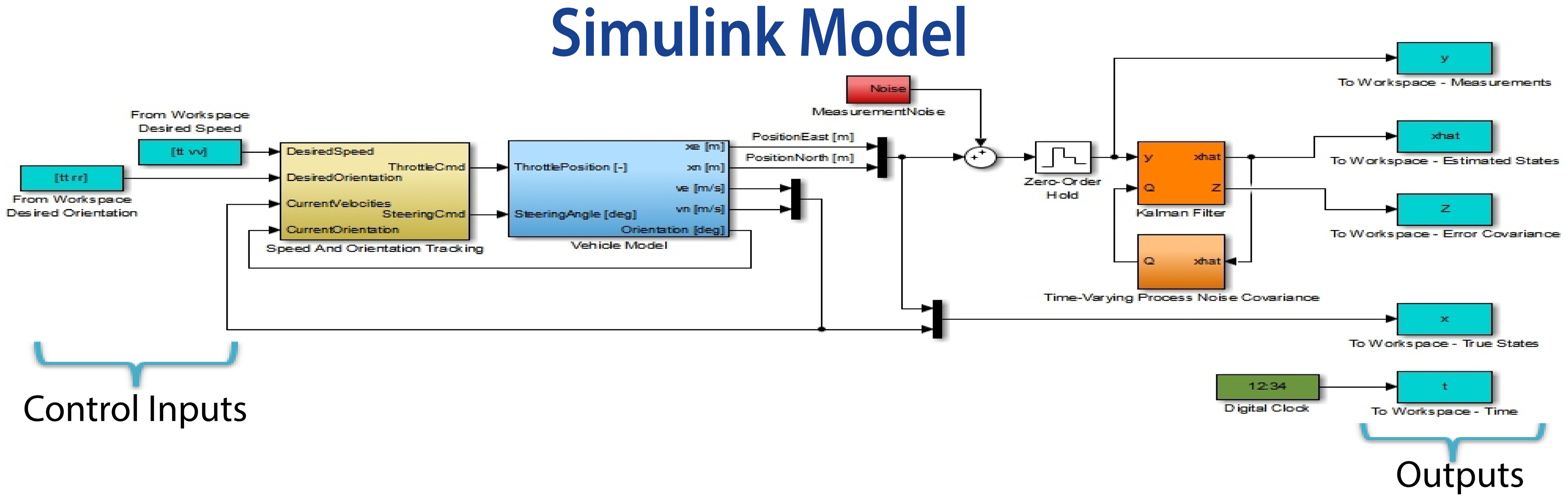
Vehicle States

- $x_e(t)$ East position [m]
- $x_n(t)$ North position [m]
- $s(t)$ Speed [m/s]
- $\theta(t)$ Orientation from East [deg]

Vehicle Parameters

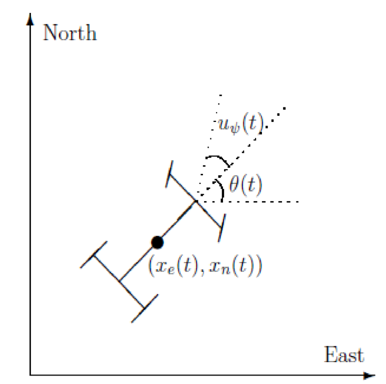
- $P = 100000$ Peak engine power [W]
- $A = 1$ Frontal area [m^2]
- $C_d = 0.3$ Drag coefficient [Unitless]
- $m = 1250$ Vehicle mass [kg]
- $L = 2.5$ Wheelbase length [m]

Simulink Model



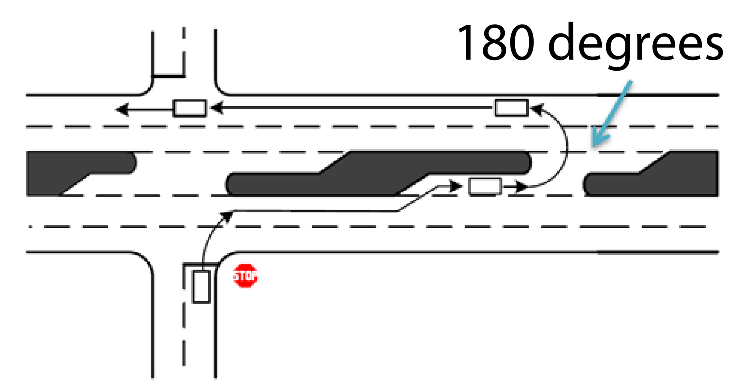
The car model is implemented in the subsystem. The Simulink model contains two PI controllers for tracking the desired orientation and speed for the car. This gives the option for specifying various operating conditions for the car and testing the Kalman filter performance.

Kalman Filter Design



•Kalman filter design and vehicle model to estimate position and velocity based on noisy position measurements (GPS sensor). Vehicle can move freely in two-dimensional space without any constraints.

•Design and test Kalman filter performance by simulating a U-Turn with the 4WS control strategy (curved trajectory of 180 degrees).

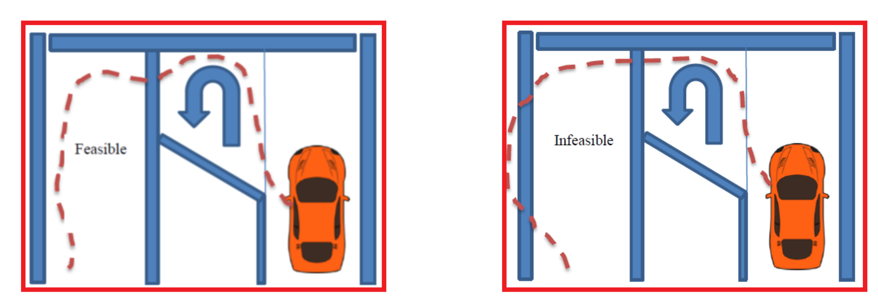


Scenario (U-Turn will be simulated at t = 260s)

•At *t = 0* vehicle is at $x_e(0) = 0$, $x_n(0) = 0$ and is stationary. Heading east, the vehicle accelerates to *25m/s*. Then the vehicle decelerates to *5m/s* at *t = 50s*.
•At *t = 100s*, it turns toward north, accelerates to *20m/s*.
•At *t = 200s*, the vehicle makes another turn toward west. It then accelerates to *25m/s*.
•At *t = 260s*, the vehicle decelerates to *15m/s* and makes a constant speed 180 degree turn.
•Work in progress includes simulating the Simulink model in Matlab, plotting actual, measured, and Kalman filter estimates of vehicle position, and analyzing the performance of the Kalman filter design.

Future Work

•Focus on variations in road conditions in order to investigate robustness of proposed control strategy.
•Track a custom 4WS robotic platform and implement closed-loop control for executing a specific maneuver autonomously in GPS denied environment.
•Use petri-net mathematical modeling for safety critical selection of feasible driving maneuvers.



References

[1] Fijałkowski, Bogdan T. Automotive Mechatronics: Operational and Practical Issues. Vol. 2. Heidelberg: Springer, 2011. Print.