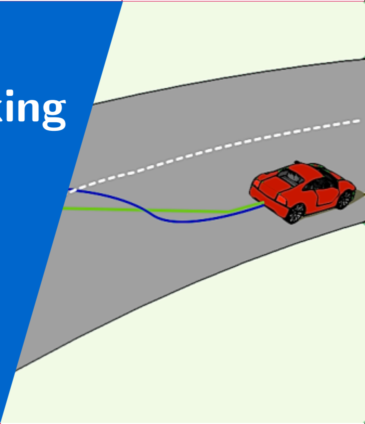
Optimal Trajectory Tracking Control for Automated Guided Vehicles



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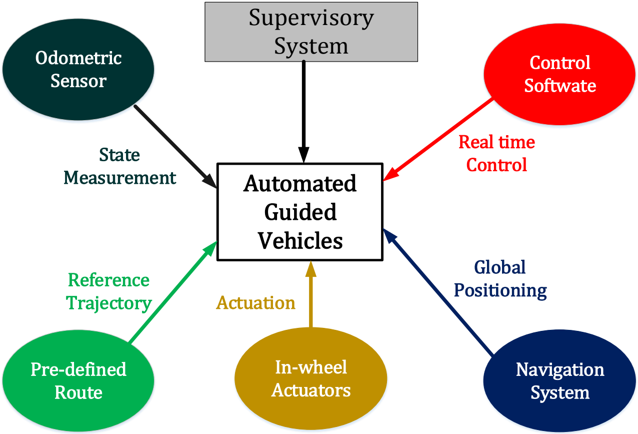
Where innovation starts

Automated Guided Vehicles (AGVs)

Supervised autonomous driving in pre-defined route.



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Different application, identical driving principal.

Research Question

How to develop a control strategy for automated guided vehicles which tracks a pre-defined trajectory ?

Features:

1. Generic for any kind of AGV with arbitrary number of wheels.
2. Handling severe cornering maneuver.
3. Carrying heavy load in elevated or banked road surface.

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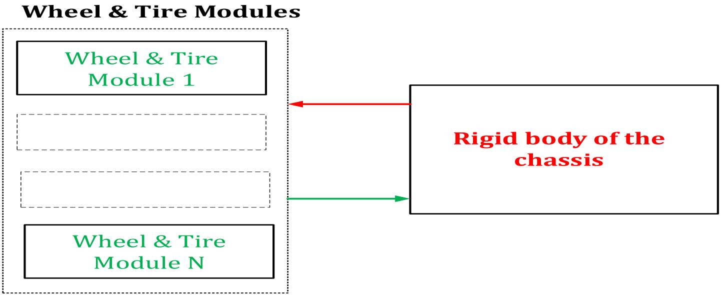
System Overview

Vehicle as multibody system.



Observation

Separate the control problem of each wheel & tire module from chassis.

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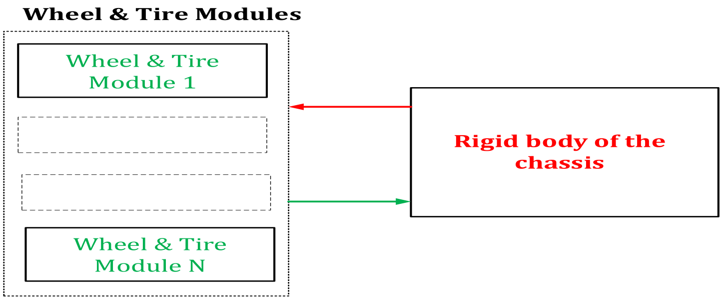

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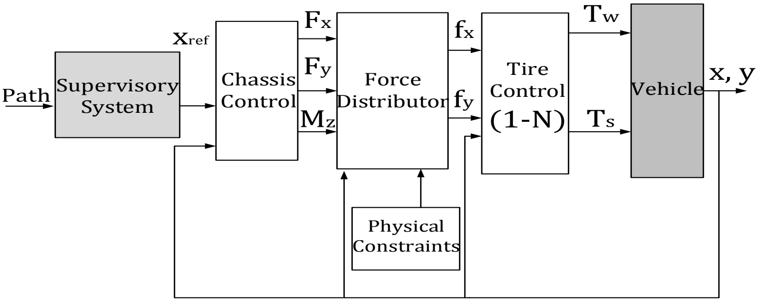
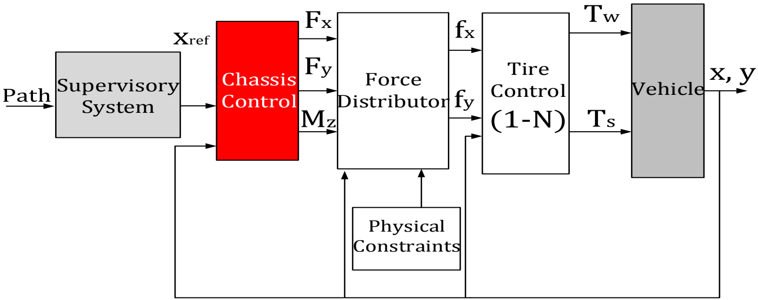
Controller Architecture



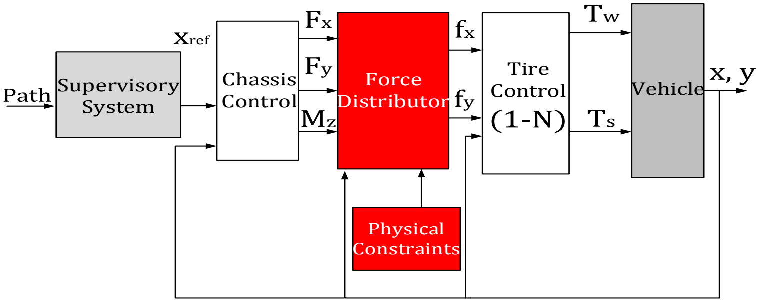
Cascade Control structure.

Controller Architecture



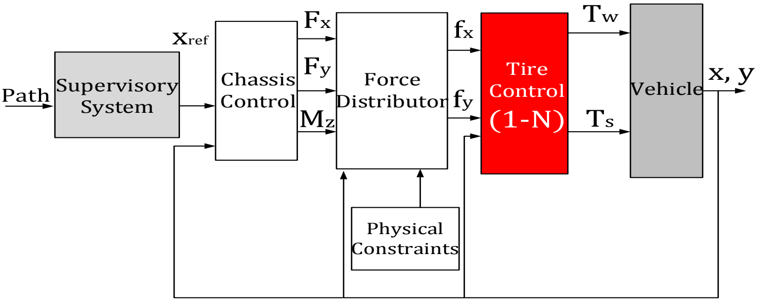
Determine the optimal longitudinal, lateral body force and also the yaw moment to be applied to the center of mass of the chassis.

Controller Architecture



Distribute the desired forces and moment from the chassis controller over N controllable wheels, under physical constraints.

Controller Architecture

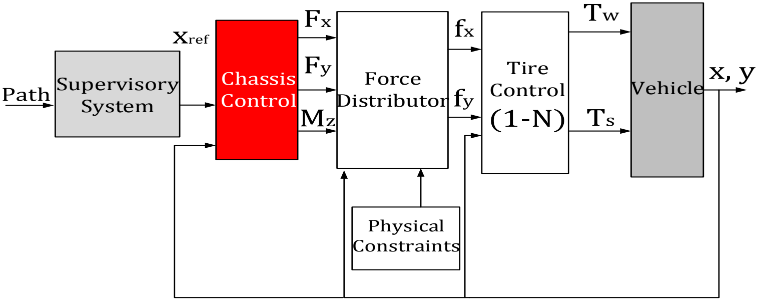


Determine the control input for each in-wheel actuator to track desired wheel-forces.

Chassis Control

Objective

Determine the desired $u_b := [F_x \; F_y \; M_z]^T$ for given $x_{\mathrm{ref}}(t)$.



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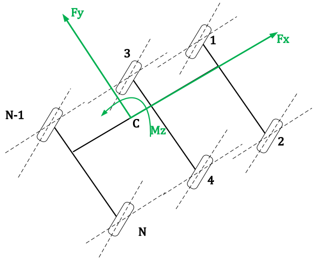

Considerations:

- Chassis as rigid body.
- Including load, new center of mass is calculated.
- Nonlinear dynamics of the chassis $\dot{x}_b = f_b(x_b, u_b)$.
- x_b includes **longitudinal velocity**, **lateral velocity**, **yaw rate**, **roll**, **roll rate**.

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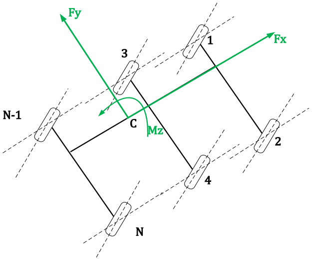

Steps:

- Divide $x_{\text{ref}}(t)$ into finite segments.
- Linearize the model for each segment.
- Apply receding horizon LQ optimal control.

Chassis Control

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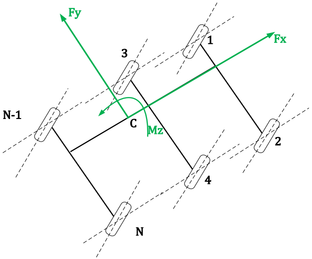
Determine the desired F_x, F_y and M_z for $x_{\text{ref}}(t)$ with $t \in [t_k, t_{k+1}]$.



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Cost Functional for k^{th} segment:

$$J(x_b{}^*, x_{\text{ref}}, u_b) = e^T(t_{k+1})\ Q_f\ e(t_{k+1})$$

$$+ \int_{t_k}^{t_{k+1}} [e^T(t)Qe(t) + u_b^T(t)Ru_b(t)]dt$$

Tracking error $e(t) := x_{\text{ref}}(t) - x_b(t)$

Chassis Control

ARE based State Feedback:

$$A^T K + KA - K\ B\ R^{-1} B^T K + Q = 0,$$

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Anticipative Feedforward:

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$$r_b(t_{k+1}) = -Q_f x_{\text{ref}}(t_{k+1})$$

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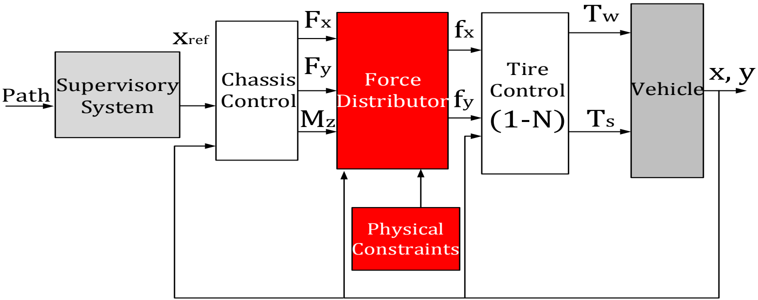
Control Input:

$$u_{b,\text{opt}}(t) = -R^{-1}B^T[K\ x_b(t) + r_b(t)].$$

Force Distributor

Objective

Destribute desired F_x, F_y and M_z to each wheel tire module.



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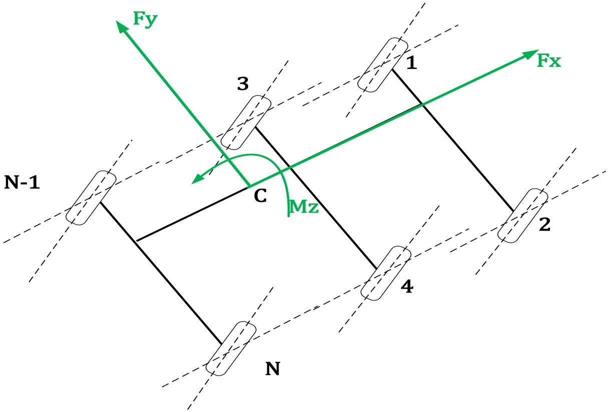

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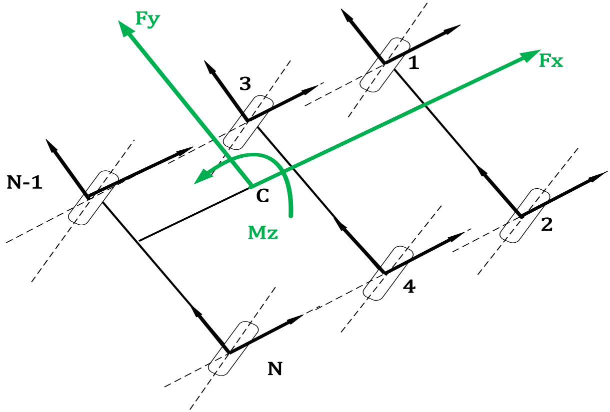

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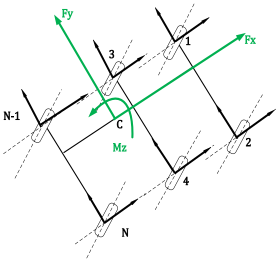

Optimization Problem:

$$\arg\min_{f} J = f^T \ W \ f$$

f is a vector containing all $f_{x,i}$ and $f_{y,i}$; $i = 1, ..N$.

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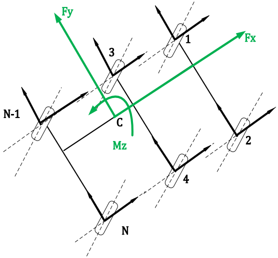

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Location of each wheel:

$$M \; f = F_d$$

F^d is the desired control signal from the outer body control.

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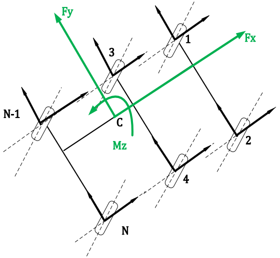

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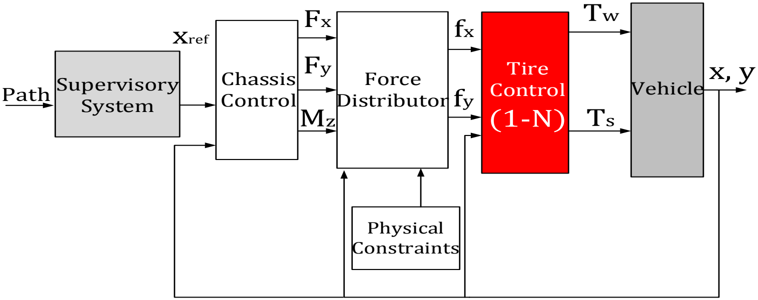
Limitation on vertical load:

$$G \; f \leq h$$

Tire Control

Objective

Determine the steering and driving actuation for generating the desired tire forces.



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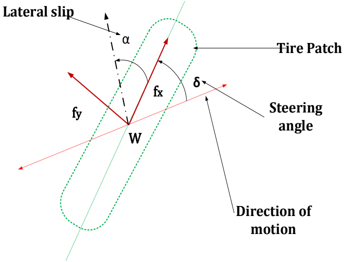

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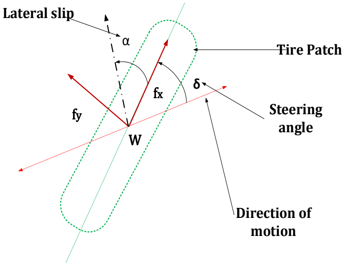

Wheel & Tire Dynamics:

- Nonlinear slip dynamics and steer-by wire dynamics:

$$\dot{x}_w = f_w(x_w) + g_w u_w, \quad y_w = h(x_w)$$

- Inputs(u_w): Steering torque and wheel torque
- Output(y_w): wheel forces in longitudinal and lateral direction.

Tire Control

Diffeomorphic Transformation:

$$\xi = \Phi(x_w),\ \dot{\xi} = b(\xi) + A(\xi)u_w$$

State Feedback Structure:

$$u_w = A^{-1}(\xi)[v - b(\xi)]$$

Virtual Control input:

$$\dot{\xi} = I\ \xi + bv_w$$

Design v_w with linear control technique.

Closed loop nonlinear system is exponentially stable.

Simulation Results

Simulation Setting

Six wheeled vehicle with independent actuation on each wheel.

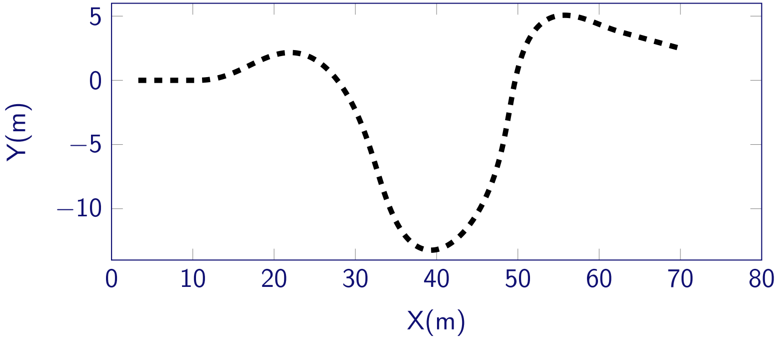

Figure: Reference Route

Simulation Results

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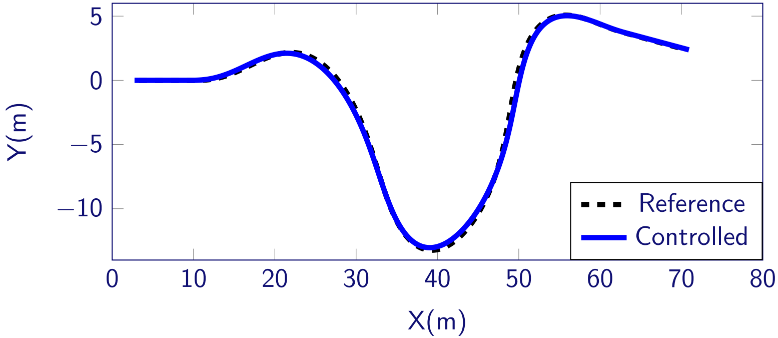

Figure: Closed loop tracking

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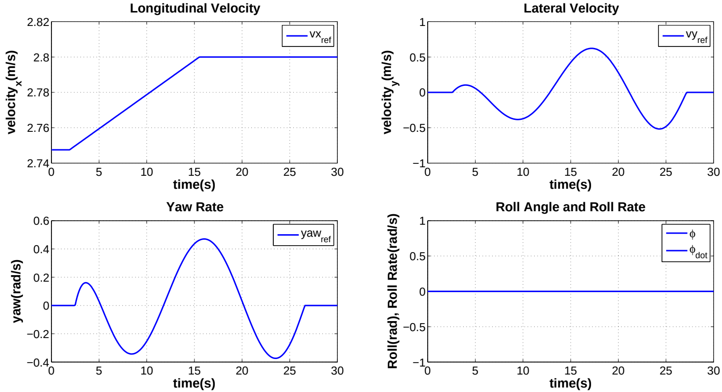

Figure: Reference state trajectory

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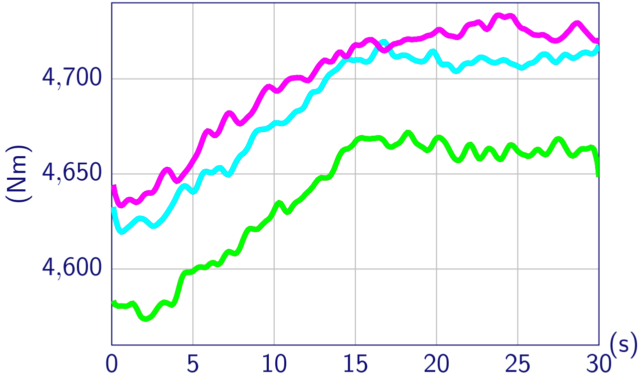

Figure: Wheel torques for the wheels on each of three axles. Green:=Front Axle; Cyan:=Center Axle; Purple:=Rear Axle.

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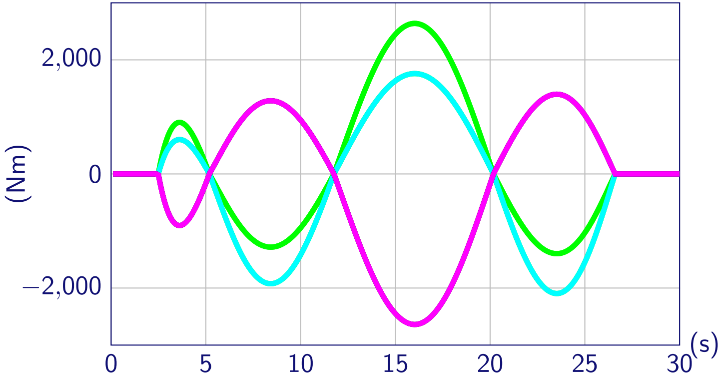

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Conclusions

- A three-stage cascade control scheme which separates the dynamics of chassis from each wheel and tire.
- The design is generic in the sense of incorporating multiple wheel & tire modules.
- Incorporating steering torque as control variable allows for handling large steering angle.

Future Recommendations

- Observer based control design in case of limited sensor measurements.
- Addressing robustness issue regarding model-plant mismatch, other uncertainties.
- Including actuator limits.

Thank You

QUESTIONS ?