MICHIGAN STATE UNIVERSITY

Internet of Mobility: Cloud-Facilitated Collaborative Sensing and Controls for Connected and Automated Vehicles

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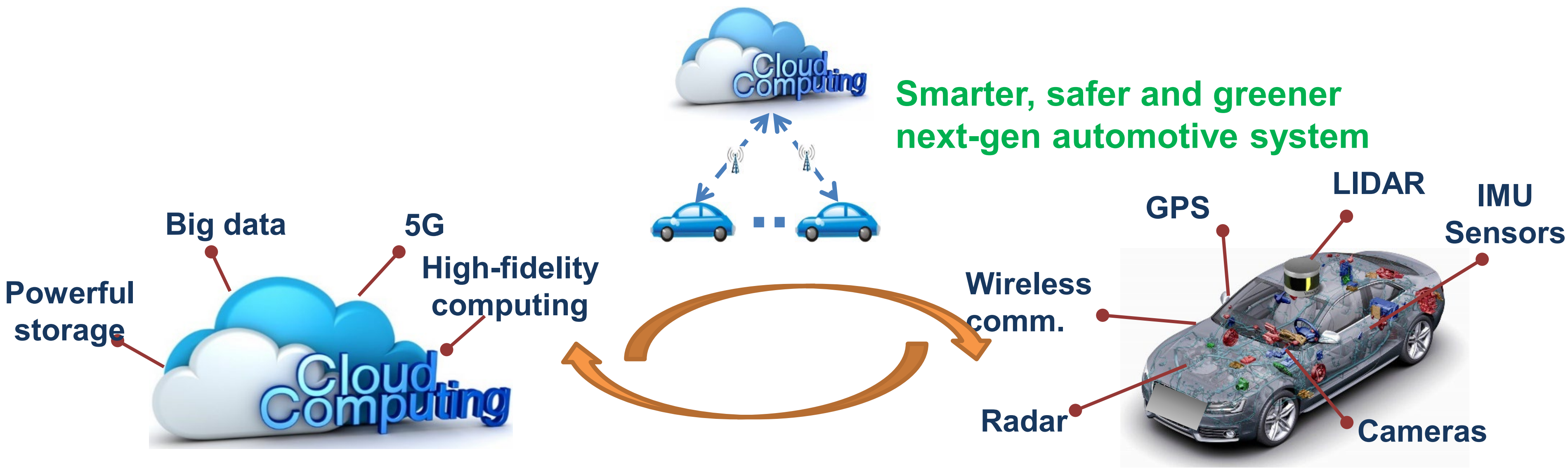
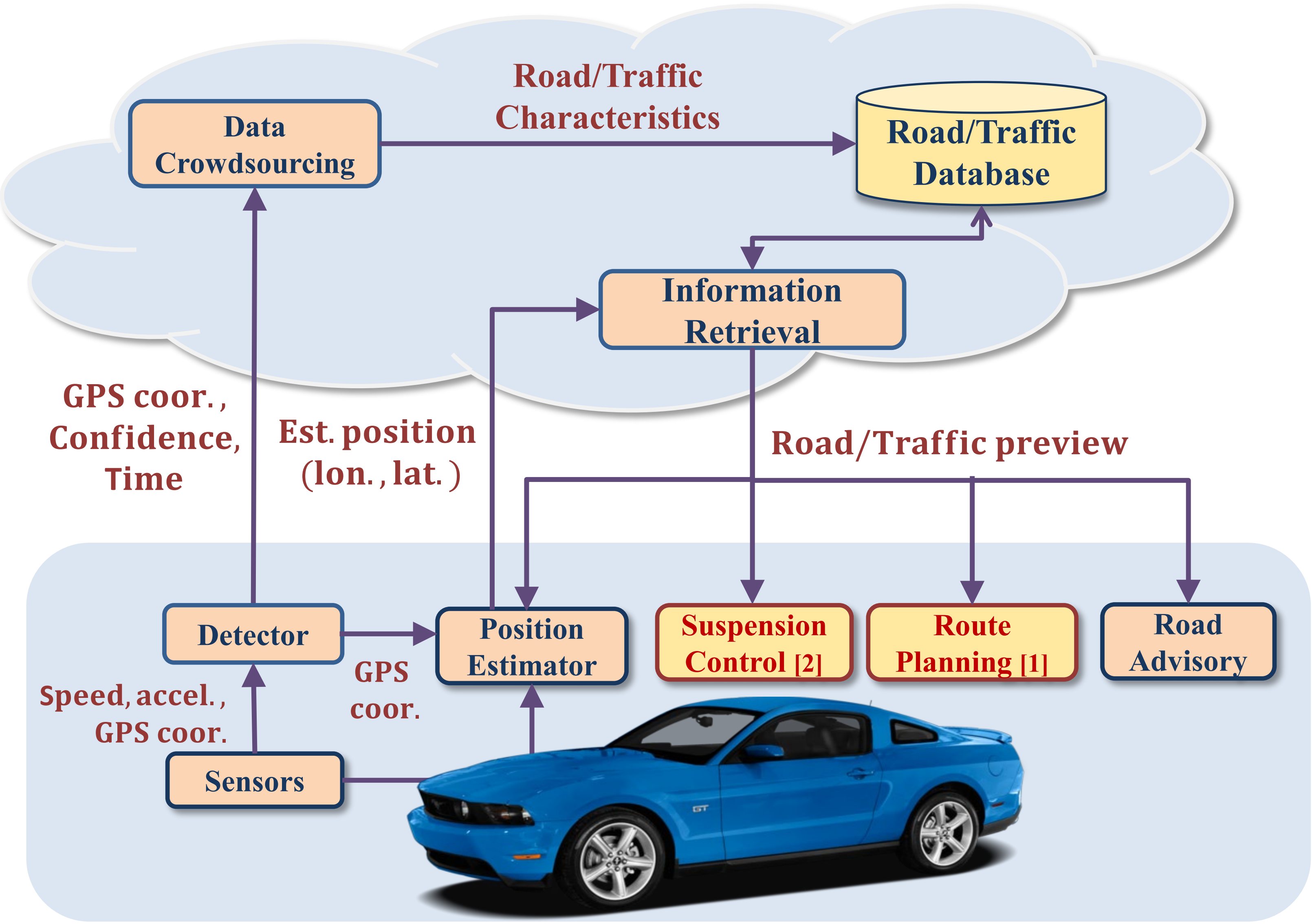
Background and Motivations

- Cloud computing shows increased promise in supporting automotive applications (5G, Big data, powerful computing and storage)
- Modern vehicles are equipped with advanced sensing and connectivity
- Seamless integration of cloud and vehicle resources to enable smarter, safer, and greener next-gen automotive systems

Vehicle-to-Cloud-to-Vehicle



Using Cars as Mobile Sensors

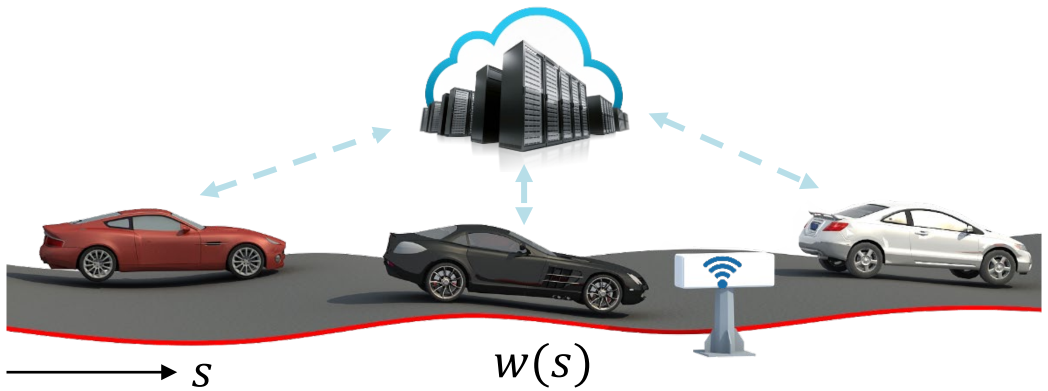


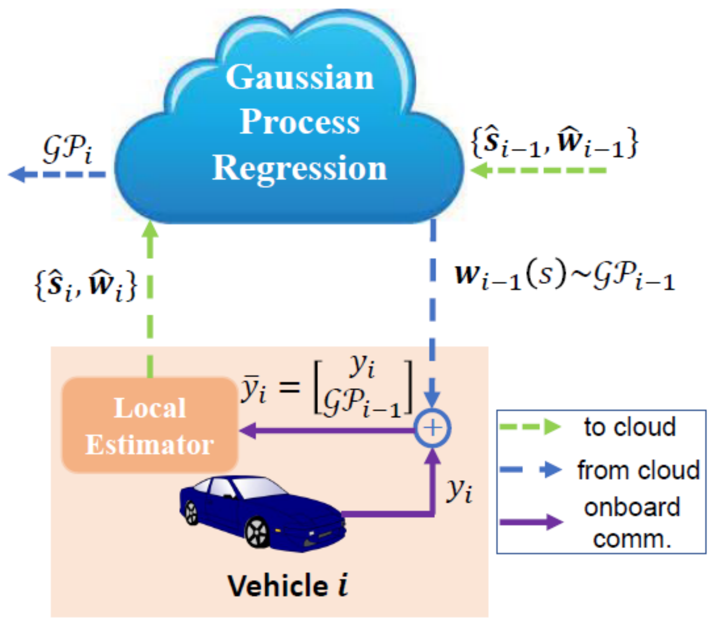
[1] Z. Li et. al., "Road disturbance estimation and cloud-aided comfort-based route planning", *IEEE Transactions on Cybernetics*, 2016

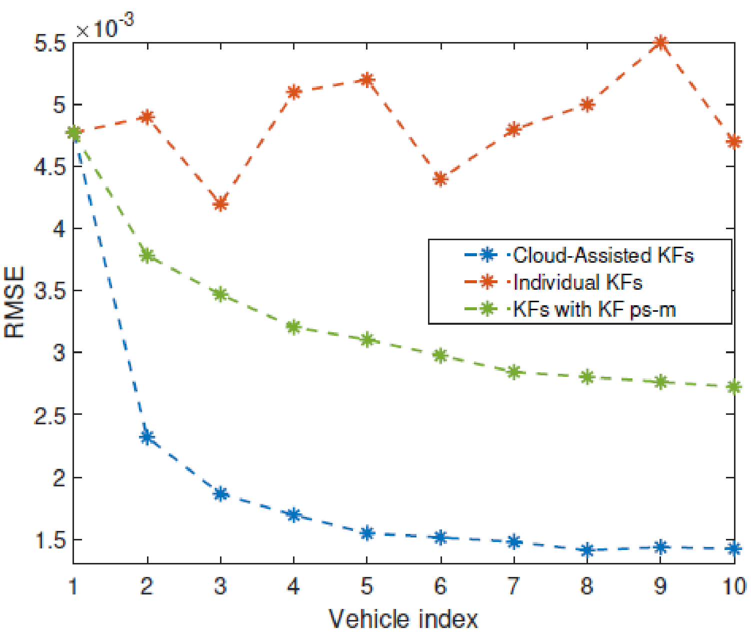
[2] M. Hajadavalloo et. al., "Simultaneous suspension control and energy harvesting through novel design and control of a new nonlinear energy harvesting shock absorber", *IEEE Transactions on Vehicular Technology*, 2022

Experiments: Anomaly Detection

Cloud-Assisted Collaborative Road Information Discovery with Gaussian Process Regression [1]



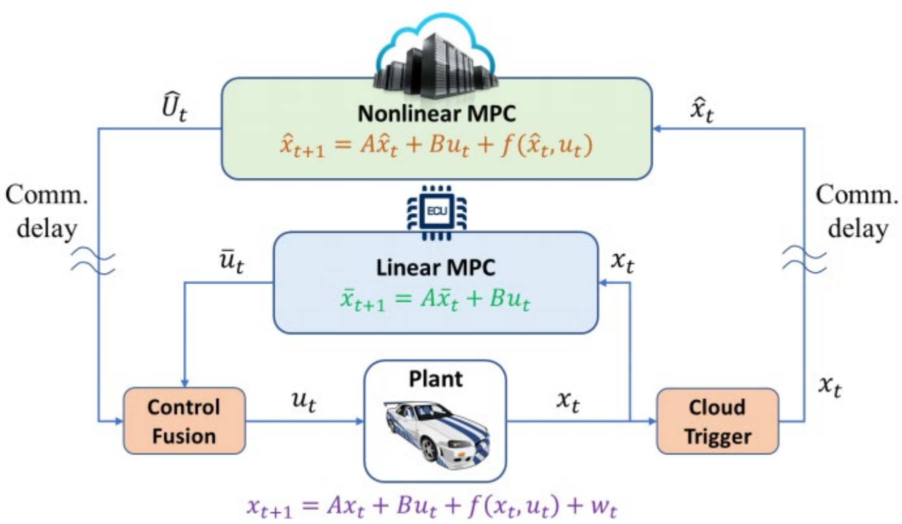




[1] M. Hajidavalloo, et. al., "Cloud-Assisted Collaborative Road Information Discovery with Gaussian Process: Application to Road Profile Estimation", *IEEE TITS*, 2022

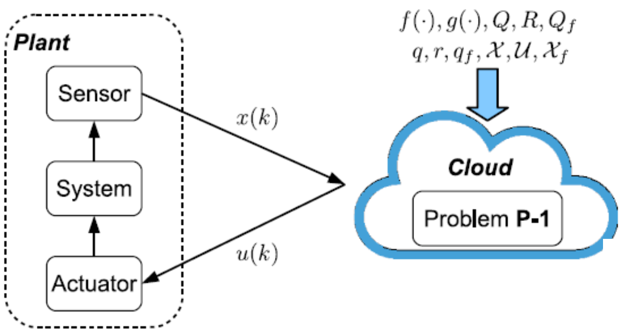
Cloud-Assisted Nonlinear Model Predictive Control [1]

- Model predictive control (MPC) is a state-of-art optimal control method that can explicitly handle constraints
- It involves solving a constrained optimization problem online at each step
- **The cloud** can run a nonlinear MPC with high fidelity model and longer prediction horizon, but it is subject to communication latency
- **Onboard** can only support a linear MPC with simplified model but it has real-time state feedback



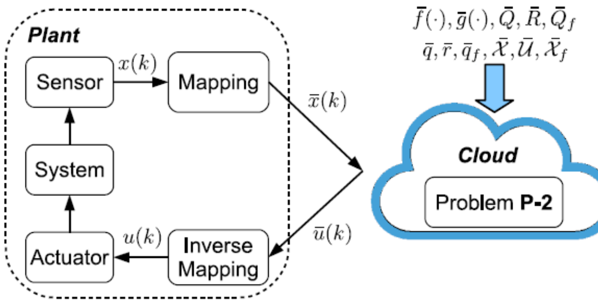
[1] N. Li et al., "Cloud-Assisted Nonlinear Model Predictive Control for Finite Duration Tasks", *IEEE TAC*, 2022

Privacy-Preserving Nonlinear Cloud-based Model Predictive Control via Affine Masking

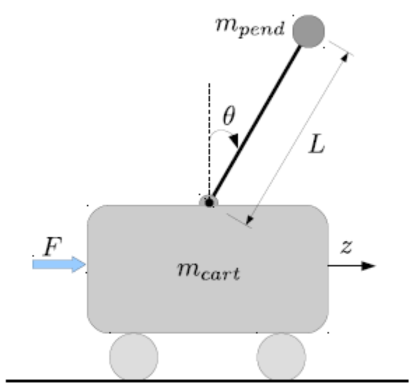


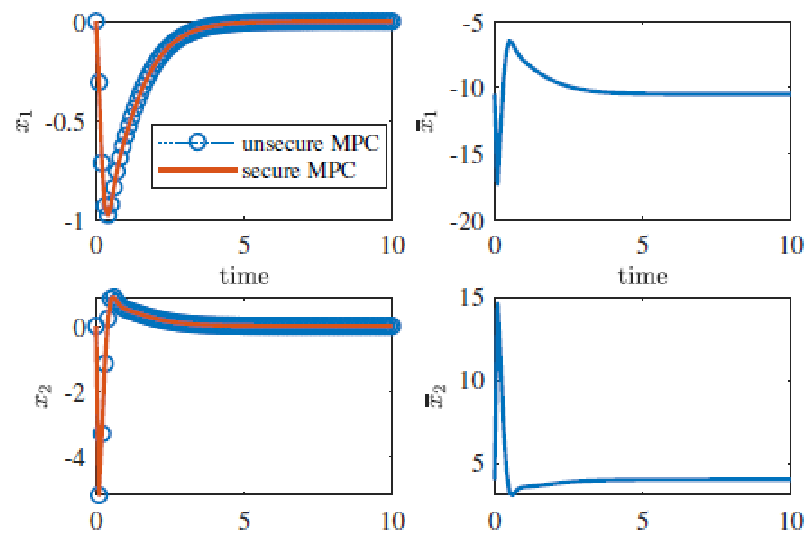
$$\bar{x}(k) = \iota_x(x(k)) = P_x(x(k) + t_x),$$
$$\bar{u}(k) = \iota_u(u(k)) = P_u(u(k) + t_u),$$

$$\bar{f}(\bar{x}(k)) = P_x\left(f \circ \iota_x^{-1}(\bar{x}(k)) - g \circ \iota_x^{-1}(\bar{x}(k)) t_u + t_x\right),$$
$$\bar{g}(\bar{x}(k)) = P_x g \circ \iota_x^{-1}(\bar{x}(k)) P_u^{-1},$$



Definition 1 (∞-Diversity with Unbounded Diameter). *The privacy of the actual system state $x_{[0,\kappa]}$ and input $u_{[0,\kappa]}$ is preserved if 1) the cardinality of the set $\Delta_{\bar{\Omega}}(\bar{x}_{[0,\kappa]}, \bar{u}_{[0,\kappa]})$ is infinite, and 2) $Diam_{\Delta_{\bar{\Omega}}}(\bar{x}_{[0,\kappa]}, \bar{u}_{[0,\kappa]}) = \infty$.*





[1] K. Zhang et al., "Privacy-Preserved Nonlinear Cloud-based Model Predictive Control via Affine Masking", *IEEE TAC*, Under Review