RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN

On the Effects of Network Delays on an Energy-based Controller

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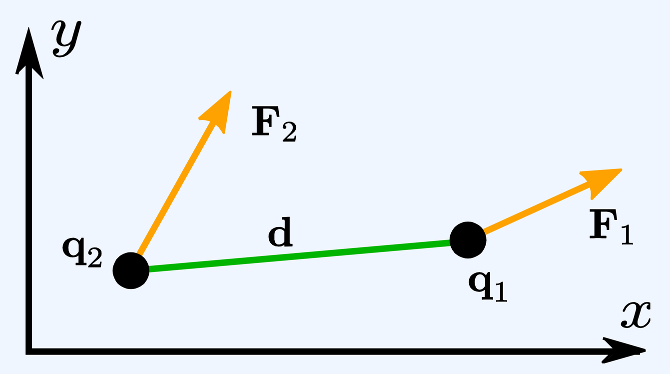
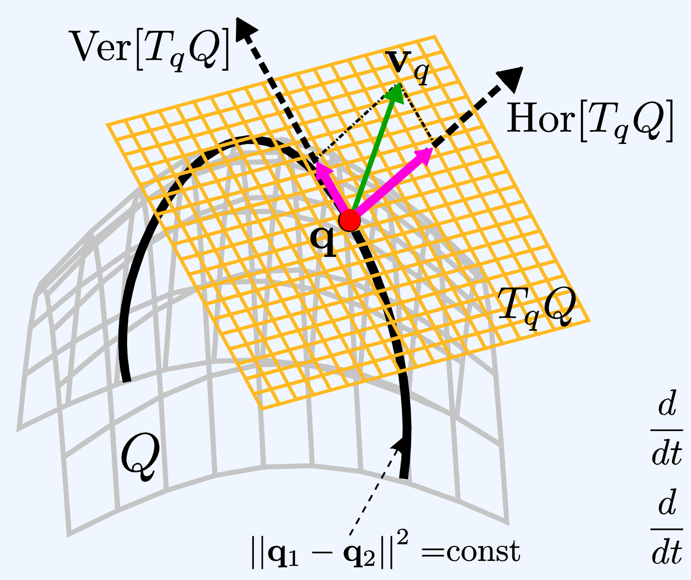
Mass Point Vehicles Control



- Vehicles modeled as mass points
- Control inputs forces to achieve desired spacing

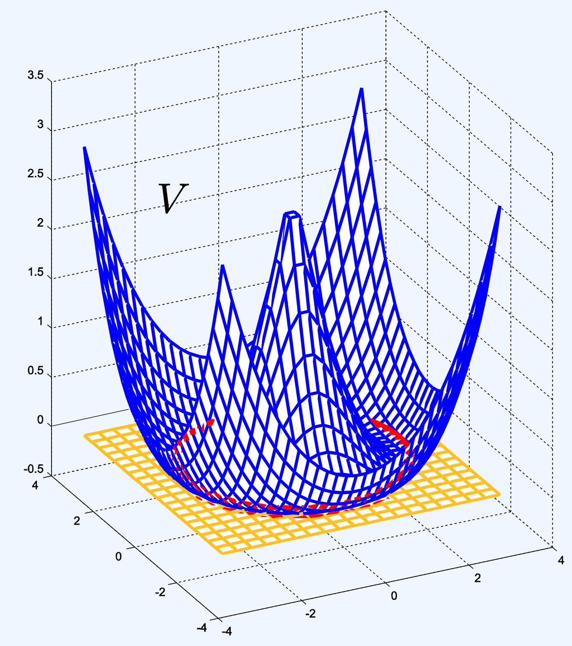


$$\frac{d}{dt}\left(\frac{\partial K}{\partial \mathbf{v}_q}\right)-\frac{\partial K}{\partial \mathbf{q}}=\mathbf{F}_{\text{kin}}$$

$$\frac{d}{dt}\left(\frac{\partial K_\alpha}{\partial \mathbf{v}_q}\right)-\frac{\partial K_\alpha}{\partial \mathbf{q}}=0$$

$$K_\alpha=2\,(1-\alpha)\,K_v+2\,\alpha\,K_h$$

- Kinetic energy shaping by splitting velocity vectors



$$V=\frac{\sigma}{2}m_1m_2\left(\|\epsilon\mathbf{q}\|-d_S\right)^2$$

- Potential energy shaping for position stability

- Dissipation for asymptotic stability

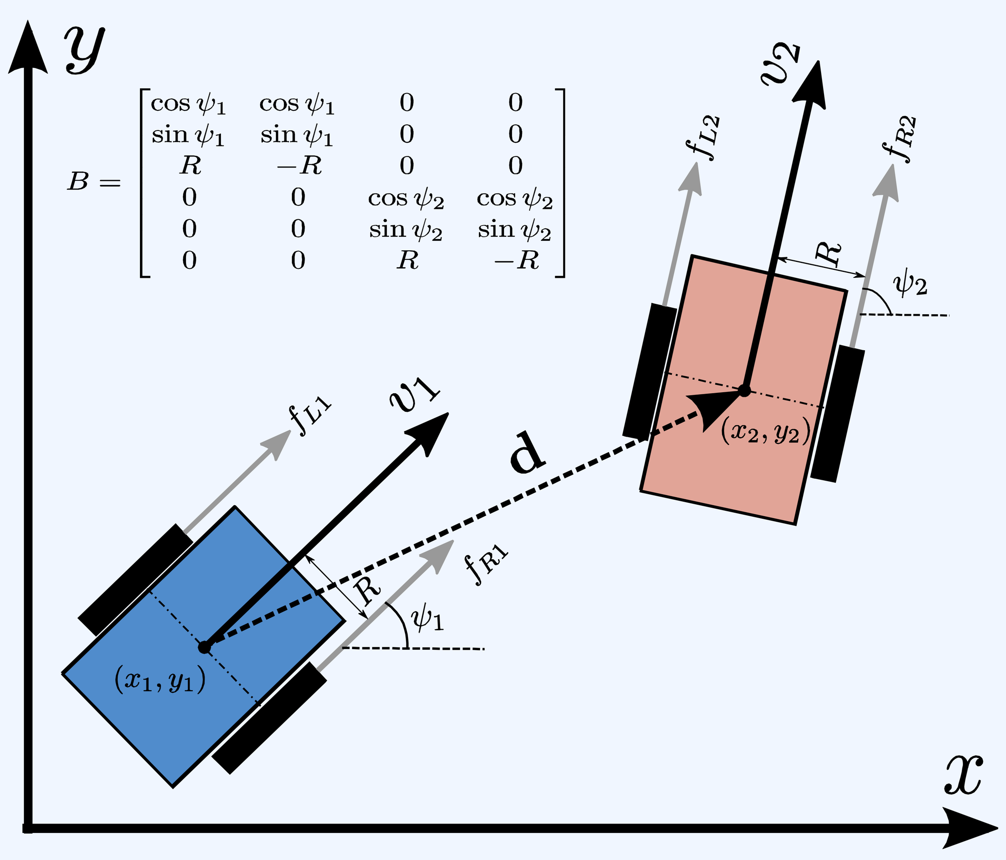
$$D=\frac{\gamma}{2}m_1m_2\left(\epsilon\mathbf{v}_q\right)^T\left(\epsilon\mathbf{v}_q\right)$$

- Overall control law

$$\mathbf{F}=\mathbf{F}_{\text{kin}}+\mathbf{F}_{\text{diss}}+\mathbf{F}_{\text{pot}}$$

$$\begin{cases}\mathbf{F}_{\text{pot}}=-\frac{\partial V}{\partial \mathbf{q}}\\ \mathbf{F}_{\text{diss}}=-\frac{\partial D}{\partial \mathbf{v}_q}\end{cases}$$

Energy-Based Controller for Nonholonomic Vehicles



Nonholonomic models

- Generation of velocities satisfying nonholonomic constraints

  $\Delta_q \ni \mathbf{v}_q=\mathbf{S}\,\mathbf{n}\,,\quad \mathbf{C}^T\mathbf{S}=\mathbf{0}$

- Modified kinetic energy shaping using Lagrange multipliers

$$\frac{d}{dt}\left(\frac{\partial K}{\partial \mathbf{v}_q}\right)-\frac{\partial K}{\partial \mathbf{q}}=\mathbf{C}\,\Lambda+\mathbf{B}\,\mathbf{U}$$

$$\frac{d}{dt}\left(\frac{\partial K_\alpha}{\partial \mathbf{v}_q}\right)-\frac{\partial K_\alpha}{\partial \mathbf{q}}=\mathbf{C}\,\Lambda+\mathbf{F}_{\text{diss}}+\mathbf{F}_{\text{pot}}$$

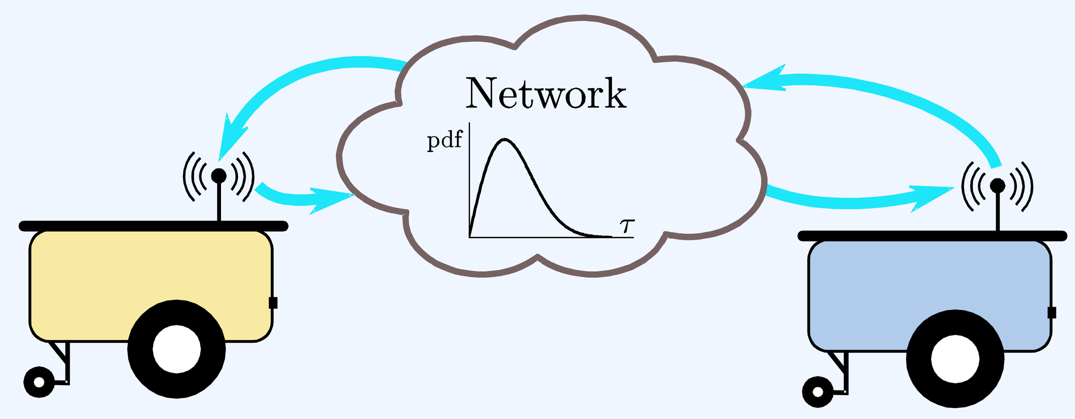
- Modified dissipation

  $\mathbf{F}_{\text{diss}}=-\gamma\,\mathbb{G}\,\epsilon^T\epsilon\,\mathbf{S}\,\mathbf{n}$

- Control law: $\mathbf{U}=\left(\mathbf{S}^T\mathbf{B}\right)^{-1}\mathbb{G}_r\,\dot{\mathbf{n}}$

- The controller can be understood in terms of energy contributions
- Stability can be checked using the total energy as a Lyapunov function candidate
- The consideration of nonholonomic constraints can be easily accomplished in the Lagrange framework

Network Model



Vehicles' communication over WLAN

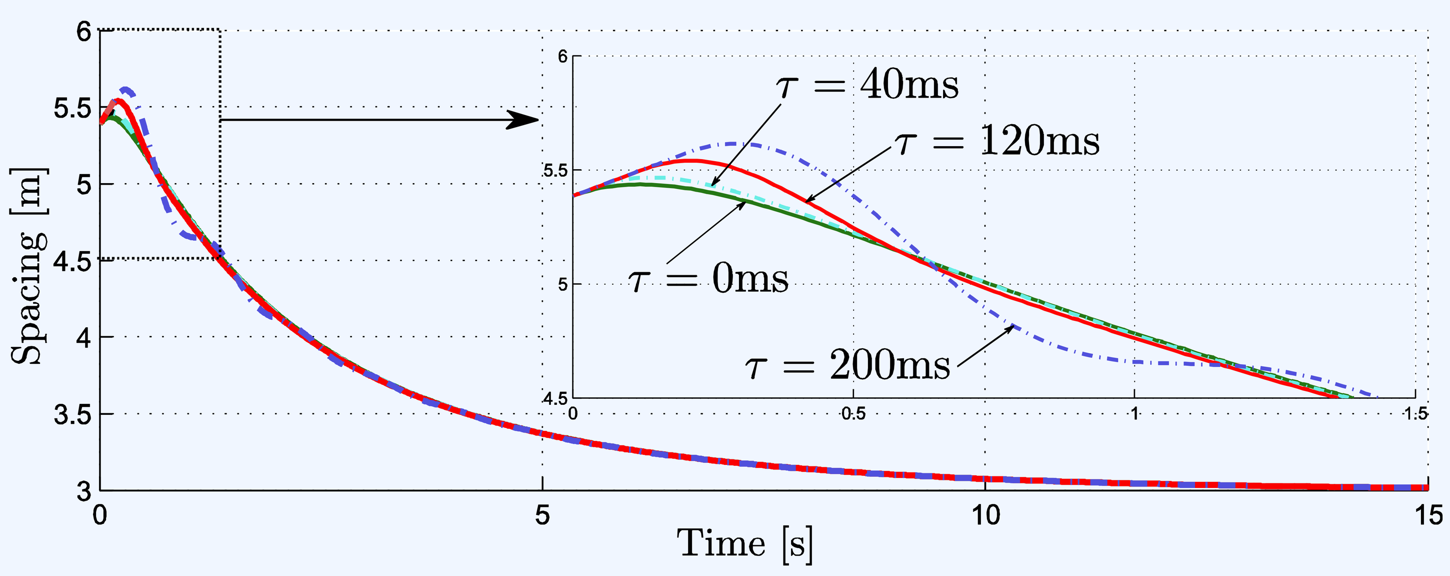
- Chanel modeled with a Rayleigh distribution

$$f\left(\tau,\mu\right)=\frac{\tau}{\mu^2}\exp\left(\frac{-\tau^2}{2\mu^2}\right)$$

- Spacing is calculated using only transmitted information
- Ethernet with UDP protocol (no retransmitting)
- Network model can not be considered in the energy-based controller design

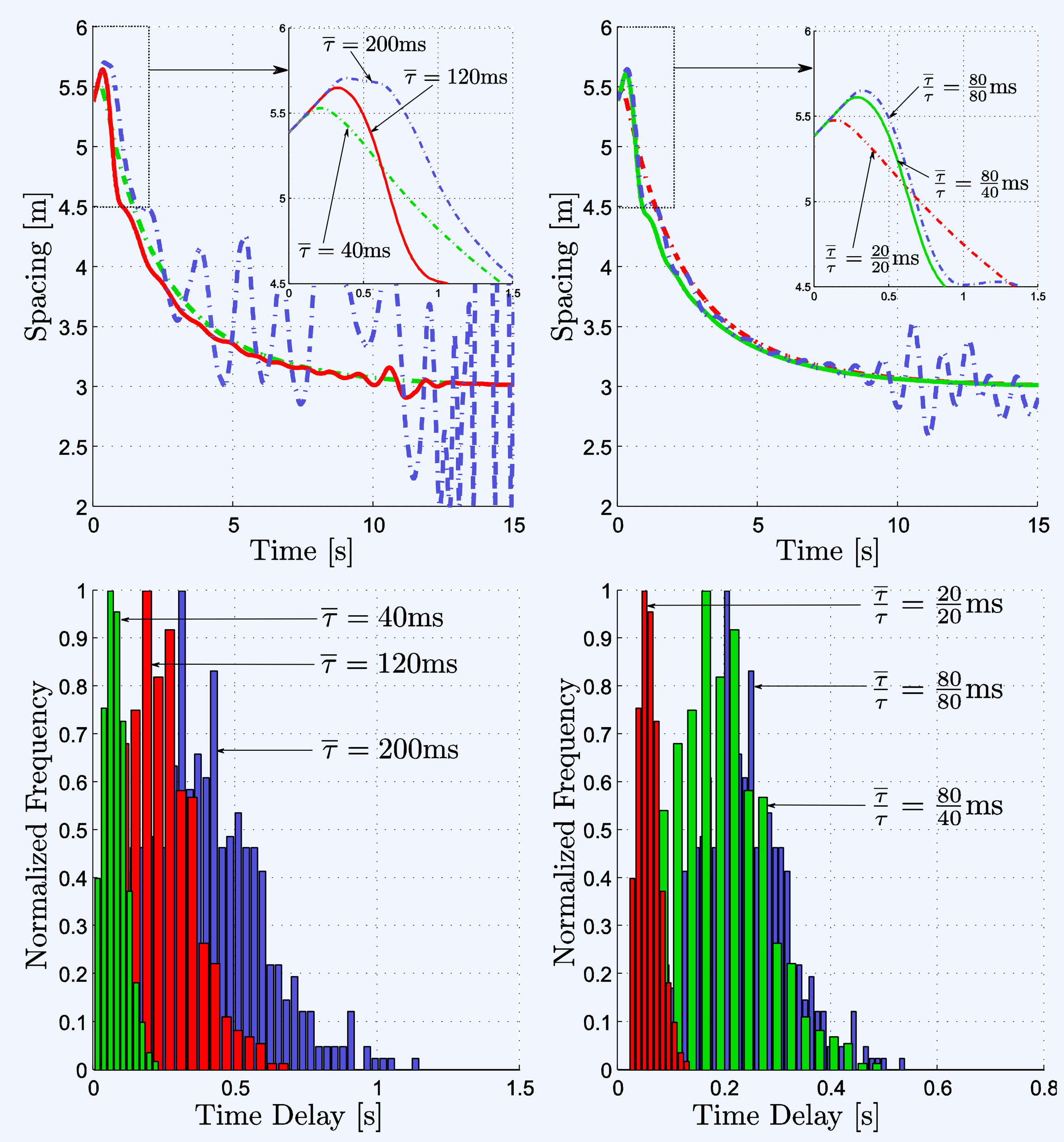
Simulation Results

- Desired spacing is 3m
- Initialization with velocity and position errors
- Stable behavior up to 200ms observed



Spacing for nominal case and with constant time delay

- Random delays are simulated with and without constant component
- The presence of random delay deteriorates the controller performance
- The sensibility to the time delays is due to the model based approach
- Sensor fusion using spacing sensors can improve performance



Spacing for random time delays (also with constant component)