Decentralized model predictive control for smooth coordination of automated vehicles at intersection

(Jun) Xiangjun Qian, Jean Gregoire, Arnaud de La Fortelle, Fabien Moutarde

ECC’15, 17 July 2015
Center for Robotics, Ecole des Mines de Paris
Introduction

[de La Fortelle et al, 2014]
Coordination of automated vehicles in conflicting scenarios

Representative scenario
A Mesoscopic – Microscopic problem
• Mesoscopic traffic control: efficiency, deadlock avoidance, etc
• Microscopic vehicle control: safety, fuel economy, comfort, etc

Interests of traffic authorities and vehicles are not aligned

We propose a mathematical framework that separates the coordination problem into two problems. The focus of this paper is on vehicle control
Literature


...
• System Model
• Priority-based Coordination
• MPC Problem Formulation
• Simulations
• Conclusion
System Model
Setting:
- a collection of robots
- fixed geometric paths
- Non-decreasing trajectory along the paths

Goals:
- Reaching goal regions
Each vehicle \( i \) controlled in acceleration (bounded)

**State:** \[ s_i = (x_i, v_i) \in S_i := \mathbb{R} \times [0, \bar{v}_i] \]

**Dynamics:**
\[
\begin{align*}
\dot{x}_i(t) &= v_i(t) \\
\dot{v}_i(t) &= u_i(t) \delta(u_i(t), v_i(t))
\end{align*}
\]

**Bounded acceleration:** \[ U_i := [u_i, \bar{u}_i] \]
Priority-based Coordination
Homotopie classes

Physical space

Coordination space

Priorities

Physical space

Coordination space

$\varphi_{2 \succ 1}(t)$

$\varphi_{1 \succ 2}(t)$

Priority relation

25/09/2015
The coordination space

Physical space

Coordination space

Priority graph

Relative order of vehicles to go through the intersection
Priority-based coordination framework

Centralized Priority Assignment Controller

Traffic related criteria;
A complex combinatorial problem

Respect priorities!
Optimization using ego vehicle related criteria;

Local Vehicle Controller

Advantage: satisfy the needs of traffic authorities and ego vehicles
MPC Problem Formulation
\[
\min_{u_i} J_i(s_i, u_i) = \min_{u_i} \sum_{k=0}^{K} L_i(s_i(k), u_i(k))
\]

subject to

\[s_i(0) = s\]

\[s_i(k) \in S_i, u_i(k) \in U_i, k = 0, ..., K\]

\[s_i(k+1) = As_i(k) + Bu_i(k), k = 0, ..., K - 1\]

\[u_i(k) \in U_{i}^{c}(s_{j \geq i}(k)), k = 0, ..., K\]

Priority preserving condition with reactive safety
MPC Formulation

Reactive safety
Objective: 

\[
\min_{u_i} \mathcal{J}_i(s_i, u_i) = \min_{u_i} \sum_{k=0}^{K} \mathcal{L}_i(s_i(k), u_i(k))
\]

subject to 

\[
s_i(0) = s
\]

\[
s_i(k) \in S_i, u_i(k) \in U_i, k = 0, ..., K
\]

\[
s_i(k+1) = As_i(k) + Bu_i(k), k = 0, ..., K - 1
\]

\[
u_i(k) \in U_i^C(s_{j \geq i}(k)), k = 0, ..., K
\]

Priority preserving condition with reactive safety

How to predict the states of prior vehicles?
Perfect case: sequential calculation

Infinit horizon MPC

Infinit horizon MPC using v1

Infinit horizon MPC using v1 and v2

Nash Equilibrium
Simple case: asynchronous calculation

Finit horizon MPC

Finit horizon MPC, assuming v1 constant

Finit horizon MPC, assuming v1 and v2 constant
Better case: asynchronous calculation

Approximating Nash Equilibrium
Simulations
Example: Reactive Safety

Reactive safety
Example: A snapshot of the overall system
Conclusion
• The conflict resolution problem => priority-based approach:
  • Priority assignment
  • Priority preserving control

• Next steps
  • Efficient priority assignment methods
  • Implementation on automated vehicles (Scania trucks)
  • Manually driven vehicles
Thank you