MPC-based Traffic Control with Vehicle Networks

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Background

Highway congestion

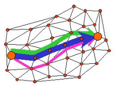
Highway congestion is imposing an intolerable burden on urban residents

Congestion occurs when vehicle's velocity variation propagates to following vehicles

It is difficult for human drivers to recognize tiny changing of the precede vehicle's velocity

Approaches

There are various approaches to improve congestion
They can be classified as
macro perspective and micro perspective



Macro perspective: On-ramp control, Transportation Network
Micro perspective: Vehicle Platoon Control

P. Varaiya, "Smart Cars on Smart Roads: Problems of Control", *IEEE Transactions on Automatic Control*, Vol. 38, No. 2, Feb. 1993

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Orientation of study

Situation setting

There are two main situation among congestion avoiding researches

Highway road model

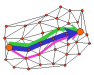
- a few merge
- no ramp
- straight

→Simple situation

Urban city road model

Two perspectives

Macro perspective [1],[2],[3]
Considering hole highway or highway network
Controlled objects are highway equipments such as on-ramp, sign, …



Micro perspective[4],[5]
Considering one lane vehicle platoon
Controlled objects is each vehicle

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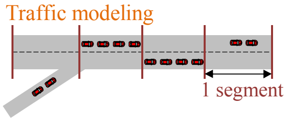
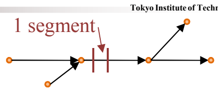
Macro Perspective[1],[2],[3]

Traffic modeling





Directed graph model
Link: highway
Node: connection, city

Dynamics

Consider link i,

$$\rho_i(k+1) = \rho_i(k) + f_i(q_i, q_{i,in}, q_{i,out})$$

ρ_i:traffic density $q_{i,in}$:inflow
q_i:traffic flow $q_{i,out}$:outflow

$q_{i,in}$ link i ρ_i, q_i $q_{i,out}$

This approach deals with vehicle density, flow
→Neglecting each vehicle dynamics or internal vehicle state

Solution

Controlling on-ramp or sign with MPC
Solving optimal allocation problem

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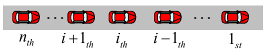
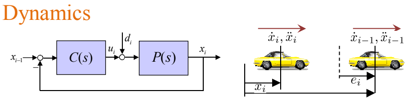
Micro Perspective[4],[5]

Traffic modeling



Consider a n-vehicles platoon in one lane highway

Dynamics



x_i : ith vehicle's position
u_i : input
d_i: disturbance
e_i : error

Each vehicle has a same LTI SISO plant/controller
Reference is precede vehicle's position, output is own vehicle position
→Each vehicle doesn't consider external information but account disturbance

Solution

Find the condition in which we can find a controller that achieves String Stability

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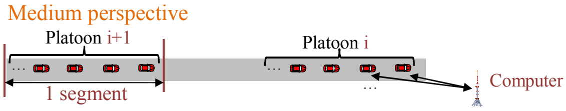
Purpose of Study

Improvement tips

Macro perspective: neglecting a vehicle dynamics
Micro perspective: don't consider external information

Combine two perspective
→Compensating each other's problem

Medium perspective



Consider several n-vehicles platoons in one lane highway
1 platoon can be interpreted as 1 segment

Every vehicles can contact to computer and get external Information
Computer controls signs or on-ramp to regulate each segment

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Future Works

Control of Preferences in Social Networks[8]

$x_{k+1}^l = Ax_k^l + B\varphi(u_k^l, u_k^{-l})$ x_k^l : Proclivity of consumers
A : Network(chain)
$\varphi(u_k^l, u_k^{-l})$: Input(advertisement) from l company

Formulating advertisement-diffusion model and deriving optimal advertising strategies

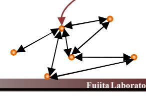
⇨ Optimal strategy is concentrate to the most effective consumer

Application

$x_{k+1} = Ax_k + Bu$ x_k : Position of vehicles
A : Communication structure

Formulating vehicle communication model and deriving optimal input strategies?

Advertizing



Schedules

Preceding period(MPC-based Traffic Control)

- Survey [2][6][7][8]
- Modeling Medium perspective
- Deciding evaluation function
- Applying PMC to the model
- Simulation

Latter period(Determination of the optimal vehicle control strategy)

- Deciding state equation
- Searching optimal control algorithm
- Simulation

- Combining two study
- Simulation, comparing

[1] L. D. Baskar, B. D. Schutter and H. Hellendoorn, "Hierachical Traffic Control and Management with Intelligent Vehicle," *Proc. of 2007 IEEE Intelligent Vehicles Symposium(IV07)*, pp. 834-839, 2007
[2]R. C. Carlson, I. Papamichail, M. Papageorgiou, "Local Feedback-based Mainstream Traffic Flow Control on Freeways Using Variable Speed Limits," *Proc. of the 13th International IEEE Annual Conference on Intelligent Transportation systems*,pp. 513-518, 2010
[3] G. Como, K. Savla, D. Acemoglu, M. A. Dahleh and E.Frazzoli, "On Robustness Analysis of Large-scale Transportation Networks,“ *International Symposium on Mathematical Theory of Networks and Systems,* pp.2399-2406, 2010
[4] S. Klinge and R. H. Middleton, "Time Headway Requirements for String Stability of Homogeneous Linear Unidirectionally Connected Systems, " *Proc. of the 48th IEEE Conference on Decision and Control*, pp. 1992-1997, 2009
[5] P. Seiler, A. Pant and K. Hedrick, "Disturbance Propagation in Vehicle Strings," *IEEE Transactions on Automatic Control*, vol. 49, No. 10, pp. 1835-1841, 2004

[6] L. D. Baskar, B. D. Schutter and H. Hellendoorn, "Model-based Predictive Traffic Control for Intelligent Vehicle: Dynamic Speed Limits and Dynamic Lane Allocation," *Proc. of 2008 IEEE Intelligent Vehicles Sympsium(IV08)*, pp. 174-179, 2008
[7]L. D. Baskar, B. D. Schutter and H. Hellendoorn, "Dynamic Speed Limits and On-ramp Metering for IVHS Using Model Predictive Control," *Proc. of the 11th IEEE Conference on Intelligent Transportation Systems*, pp. 821-826, 2008
[8]G. C. Chasparis and J. S. Shamma, "Control of Preferences in Social Networks," *Proc. of the 49th IEEE Conference on Decision and Control* ,pp. 6651-6656, 2010

Appendix

String Stability

Definition[1]

Consider a string of N dynamic systems .the error signals $e(t)$ *depends on the disturbances* $d(t)$ *in the following manner:*

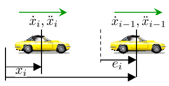
$$e(t) = H_{e,d}(s)d(t) \quad e,d \in R^n \quad H_{n,d}(s): R^N \to R^N \quad (*)$$

The system (*) is L_2 *string stable if given any* $\varepsilon > 0$ *there exist a* $\delta > 0$ *such that*

$$\|d(\cdot)\|_2 < \delta \Rightarrow \|e(\cdot)\|_2 < \varepsilon$$

Assumption

- LTI SISO plant/controller
- Each loop has relative degree
- Homogeneous loop



Deformation

$$\|d(\cdot)\|_2 < \delta \Rightarrow \|e(\cdot)\|_2 < \varepsilon$$

⇕ $\|G(s)\|_\infty = \sup_{d(t)} \frac{\|e(t)\|_2}{\|d(t)\|_2}$ [2]

$$\|H_{e,d}(s)\|_\infty < \gamma \quad \gamma = \frac{\varepsilon}{\delta}$$

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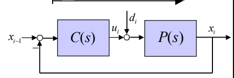

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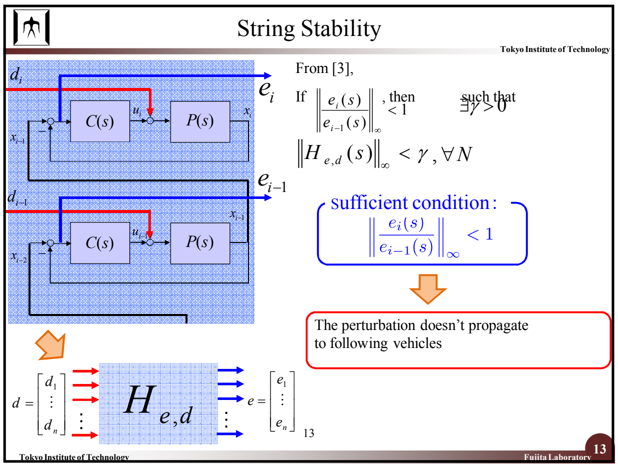
String Stability
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From [3],
If $\left\| \frac{e_i(s)}{e_{i-1}(s)} \right\|_\infty < 1$, then $\exists \gamma > 0$ such that
$\| H_{e,d}(s) \|_\infty < \gamma, \forall N$
sufficient condition : $\left\| \frac{e_i(s)}{e_{i-1}(s)} \right\|_\infty < 1$
The perturbation doesn't propagate to following vehicles
C(s)
P(s)
$H_{e,d}$
$d = [d_1 \; \vdots \; d_n]$
$e = [e_1 \; \vdots \; e_n]$
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