Highways platooning using a flatbed tow truck model

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I. INTRODUCTION
- Context
- Why platooning
- Longitudinal control policies.

II. MODELING:
- Longitudinal model
- Platoon model

III. CONTROL
- Control objectives.
- Longitudinal control

IV. STABILITY AND SAFETY
- Stability
- Robustness to actuation and sensing lag
- Discussion

V. SIMULATION
- Stability
- Comparison with CTH
- Robustness

VI. CONCLUSION AND PERSPECTIVES
I. INTRODUCTION

**Context:**
- Highways platoons,
- Longitudinal dynamics,
- Taking into account a simplified engine model,
- Using the modified CTH control law [1],
- The flatbed tow model is proposed,
- Stability and safety conditions is found,
- Simulation using TORCS,
- A platoon of 10 vehicles with $L = 1$ m,

**Scenarios:**
- platoon creation
- changing the speed
- emergency stop
I. INTRODUCTION

- Why platooning:
  - Increases traffic density.
  - Increases safety:
    - Collision (Small relative velocity).
    - No human factor.
    - Reaction time is small.
  - decreases fuel consumption.
  - decreases driver tiredness
I. INTRODUCTION

• Global Control and Local Control:
  ○ Data (at least from leader, adjacent vehicles)
  ○ Sophisticated sensors (needed, Not needed).
  ○ Adaptation in the environment (Maybe, Not needed)
  ○ Communication system (need very reliable, not needed)
  ○ Trajectory tracking and inter distance keeping (accurate, Not very accurate)
  ○ *The car is totally autonomous* (No, Yes).
I. INTRODUCTION

- Variable inter-vehicle distances (according to vehicle’s dynamic):
  - Distances are proportional to velocity in Constant Time Headway (CTH).
  - Low traffic density.
  - Stable without communication.
  - The cars can work autonomously.

\[ \Delta X = L + h v_i \]

- Constants inter-vehicle distances:
  - High traffic density.
  - The communication between vehicles is mandatory.

\[ \Delta X = L \]
II. MODELING (LONGITUDINAL MODEL)

- Newton’s law,
- The model of the engine,
- Applying the exact linearization system,
- linear system can be obtained:

\[ \ddot{x} = W \]
II. MODELING (PLATOON MODEL)

- Unidirectional spring – damper model,
- With a virtual truck running at a speed $V$,
- Classical CTH
- Modified CTH

Equivalent to flatbed tow truck model [3]:

[Diagram of platoon modeling with labeled elements representing force and velocity relationships]
III. CONTROL

- Control Objectives.
  - Keep a desired distance between the vehicles.
  - Make the vehicles move at the same speed.
  - Ensure vehicles and platoon stability.
  - Ensure vehicles and platoon safety.
  - Increase traffic density.
  - Ensure the stability and safety even in case of:
    - Entire communication loss between vehicles.
    - Existence of actuating and sensing lags.
III. CONTROL (Modified CTH)

- Modified CTH Control law:

\[ W_i = -k_a \ddot{x}_i + k_v \dot{e}_i + k_p e_i - k_p h (v_i - V) \]

- Spacing is proportional to the difference between the velocity of the vehicle and a shared velocity

- Classical CTH

\[ \Delta X_i = L + h v_i \]

- Modified CTH

\[ \Delta X_i = L + h (v_i - V) \]
IV. STABILITY AND SAFETY

- String stability definition.
  - The error must not increase when it propagate through the platoon.
  - Spacing error propagation function:
    \[ G_i(s) = \frac{e_i(s)}{e_{i-1}(s)} \]

- A sufficient condition for the stability of the platoon is:
  \[ \| G_i(\omega) \|_{\infty} \leq 1 \quad \forall \omega \quad \text{and} \quad g_i(t) > 0 \quad i = 1, 2, \ldots, N \]

- \( g_i(t) \) is the impulse response of the propagation of spacing error.
IV. STABILITY AND SAFETY

- Spacing error propagation function:
  \[ G_i(s) = \frac{e_i(s)}{e_{i-1}(s)} \]

\[
G_i(s) = \frac{k_v s + k_p}{s^3 + k_a s^2 + (k_v + h k_p) s + k_p}
\]

- Stability conditions:
  \[
  \begin{cases}
    k_a^2 - 2k_v - 2k_p \geq 0 \\
    k_p h^2 + 2k_v k_p h - 2k_a k_p \geq 0 
  \end{cases}
\]

  or

  \[
  \begin{cases}
    h k_a \geq 2 \\
    k_a^2 \geq 2k_v \\
    2k_v \geq k_a^2 - \xi 
  \end{cases}
\]

  or

  \[
  \begin{cases}
    h k_a \geq 2 \\
    k_a^2 \leq 2k_v \\
    2k_v \leq k_a^2 + \xi 
  \end{cases}
\]
IV. STABILITY AND SAFETY

- First spacing error propagation function:

\[ G_1(p) = \frac{e_1(p)}{a_{\text{leader}}(p)} = \frac{p + k_a}{p^3 + k_a p^2 + (k_v + h) k_p p + k_p} \]

\[ \|e_1\| \leq \left\| \frac{e_1}{a} \right\| \max(|a_{\text{max}}|, |a_{\text{min}}|) \]

- The following condition will ensure the safety for all accelerations:

\[ \|e_1\| \leq \left\| \frac{e_1}{a} \right\| \max(|a_{\text{max}}|, |a_{\text{min}}|) \leq l \]

- Safety conditions:

\[ \begin{cases} k_p \geq \frac{|a_{\text{min}}|}{l} k_a \\ k_a^4 + 8 k_p k_a + 4 \frac{a_{\text{min}}^2}{l^2} \leq 4 (k_v + k_p h) k_a^2 \end{cases} \]

or

\[ \begin{cases} k_p \geq \frac{|a_{\text{min}}|}{l} k_a \\ k_a^2 \geq 2 (k_v + k_p h) \\ (k_v + k_p h)^2 \geq 2 k_p k_a + \frac{a_{\text{min}}^2}{l^2} \end{cases} \]
V. SIMULATIONS

- 10 identical cars,
- Move on straight track,
- Comparison with the classical CTH,
- Check longitudinal string stability during:
  - stage A: Platoon Creation (zero to 40km/h),
  - stage B: Changing the speed (40km/h to 140km/h)
  - stage C: Emergency stop (Hard Braking)
- Check safety
  - stage C: Emergency stop at high speed (140km/h) by applying maximum allowed deceleration.
V. SIMULATIONS

- Maximum acceleration and deceleration $\pm 5 \text{ m/s}^2$
  - exceeds the comfort acceleration,
  - exceeds the ability of many vehicles,
V. SIMULATIONS

- Comparison with the classical CTH
  - Classical CTH
  - Modified CTH
V. SIMULATIONS

- Stage A: Platoon Creation (zero to 40km/h),
V. SIMULATIONS

- stage B: Changing the speed (40km/h to 140km/h)
  - The platoon is stable,
V. SIMULATIONS

- stage C: Emergency stop (Hard Braking)
  - The platoon is stable,
  - Safe
VI. CONCLUSION and PERSPECTIVES

- The control of highways platoons is addressed,
- Longitudinal control:
  - Using modified CTH control law,
  - Taking into account a simplified engine model.
  - The flatbed tow model is proposed,
- We have enhanced the work presented in [1], [2]:
  - Reducing the desired inter-vehicle distance to 1 m,
  - keeping the string stability,
  - Ensuring the safety.
- Simulations were done in following scenarios:
  - platoon creation
  - changing the speed
  - emergency stop
- This work opens the door to move CTH policy from research to real applications.
VI. CONCLUSION and PERSPECTIVES

- Studding safety in more critical scenarios:
  - Leader hard braking:
    - With full communication,
    - Without communication,
  - Follower hard braking:
    - With full communication,
    - Without communication,
- Communication delays and lags effects,
- Real experiments.
References

