Experimental verification of a scalable protocol for vehicle platooning

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Goal

The coordination of multi-agent systems is a well-studied problem. A suitable application is vehicle platooning. However, the study in [1] reveals that the conventional approach for simultaneously coordinating position, velocity and acceleration lacks scalability. Recently, a new scalable consensus protocol is introduced in the context of vehicle platooning, denoted by *serial consensus.* It is shown in a theoretical framework [2,3] that this new protocol has superior scalable behavior compared to the conventional approach. This work aims to provide an experimental verification of the serial consensus algorithm using a physical setup that mimics a vehicle platoon. The goal is to verify both the stability and performance.

Contributions

In this work, the theoretical superior behavior of the serial consensus protocol compared to the conventional approach is verified experimentally using a physical experimentation setup. This setup uses five mobile robots (also known as omnibots), hence mimicking a vehicle platoon. The discretized implementation of the protocol was subject to measurement noise. We first show that the implementation of the serial protocol achieves *stability.* We then demonstrate that the serial protocol also achieves *performance* in the form of string stability in the experiment. This is in contrasts with the conventional protocol.

Controlling a vehicle platoon

The coordination of a vehicle platoon is part of a bigger class of problems known as *second-order consensus* problems where the goal is to control a network of double-integrator systems using only relative feedback. We distinguish two approaches to achieve consensus.

Conventional consensus

- The conventional approach to control a vehicle platoon is to let each vehicle observe the relative position and velocity to its predecessor and then adjust its own velocity.
- The conventional control protocol can be written as

$$u_i(t) = -a_0 e_i(t) - a_1 \dot{e}_i(t).$$

- Conventional consensus yields very poor scalable performance. Theory shows that conventional consensus is string unstable, meaning that the transient error grows exponentially with the number of agents.

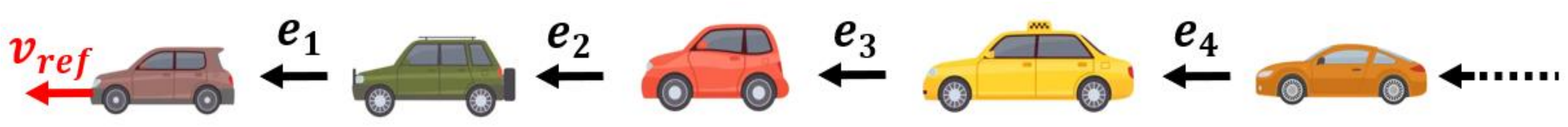

Figure 1: Communication structure of *conventional* protocol

Serial consensus

- The serial consensus protocol requires additional communication between the vehicles compared to the conventional approach. Each vehicle now also needs the relative position of its predecessor's leading vehicle with respect to this predecessor.
- The serial consensus protocol can be written as

$$u_i(t) = -a_0[e_i(t) + e_{i-1}(t)] - a_1 \dot{e}_i(t).$$

- Serial consensus yields desirable scalable performance. The paper [3] shows that conventional consensus is string stable, meaning that the transient error can be bounded.

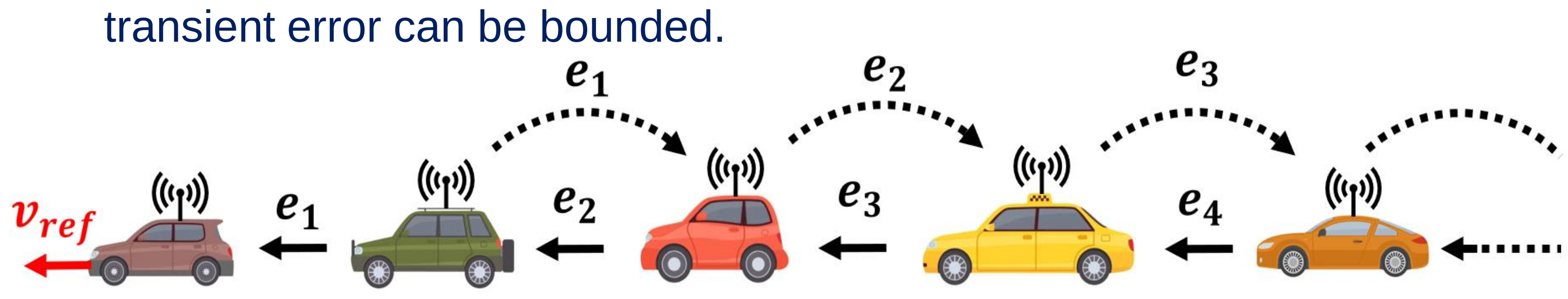

Figure 2: Communication structure of *serial* protocol

Stability

- Theoretical results [2] show that the serial protocol achieves stable consensus dynamics if the feedback gains satisfy $a_1 \geq 2\sqrt{a_0}$.
- Here we present a theoretical relaxation of this stability condition.
- The relaxed stability bound is verified experimentally using the physical setup with five omnibots. The experiments are performed with a circular vehicle platoon.

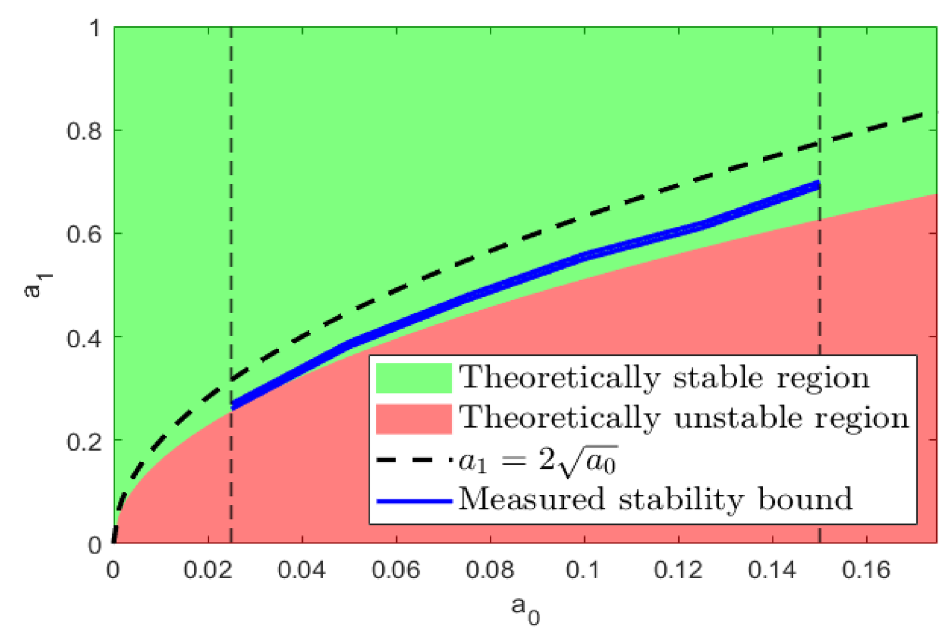

Figure 3: Theoretical and measured stability bound

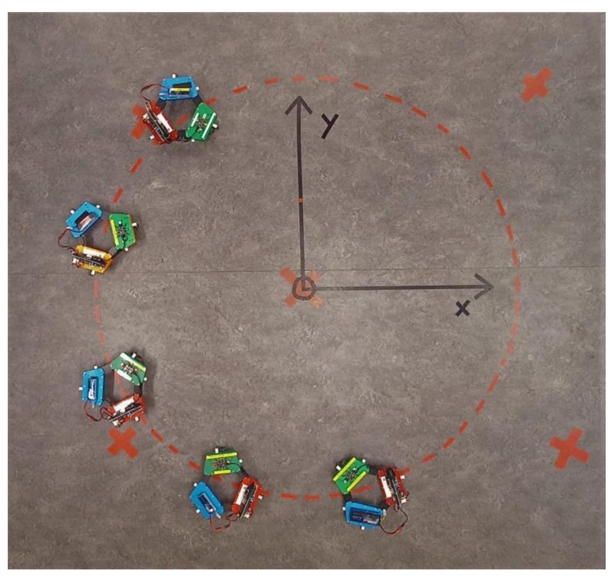

Figure 4: Experimentation setup (top view)

Performance

- The performance of both protocols are verified by performing experiments using a linear vehicle platoon with 40 vehicles.
- The transient response of the conventional protocol increases exponentially with the number of agents.
- The transient response of the serial protocol remains bounded, highlighting the superior performance of the serial consensus approach.

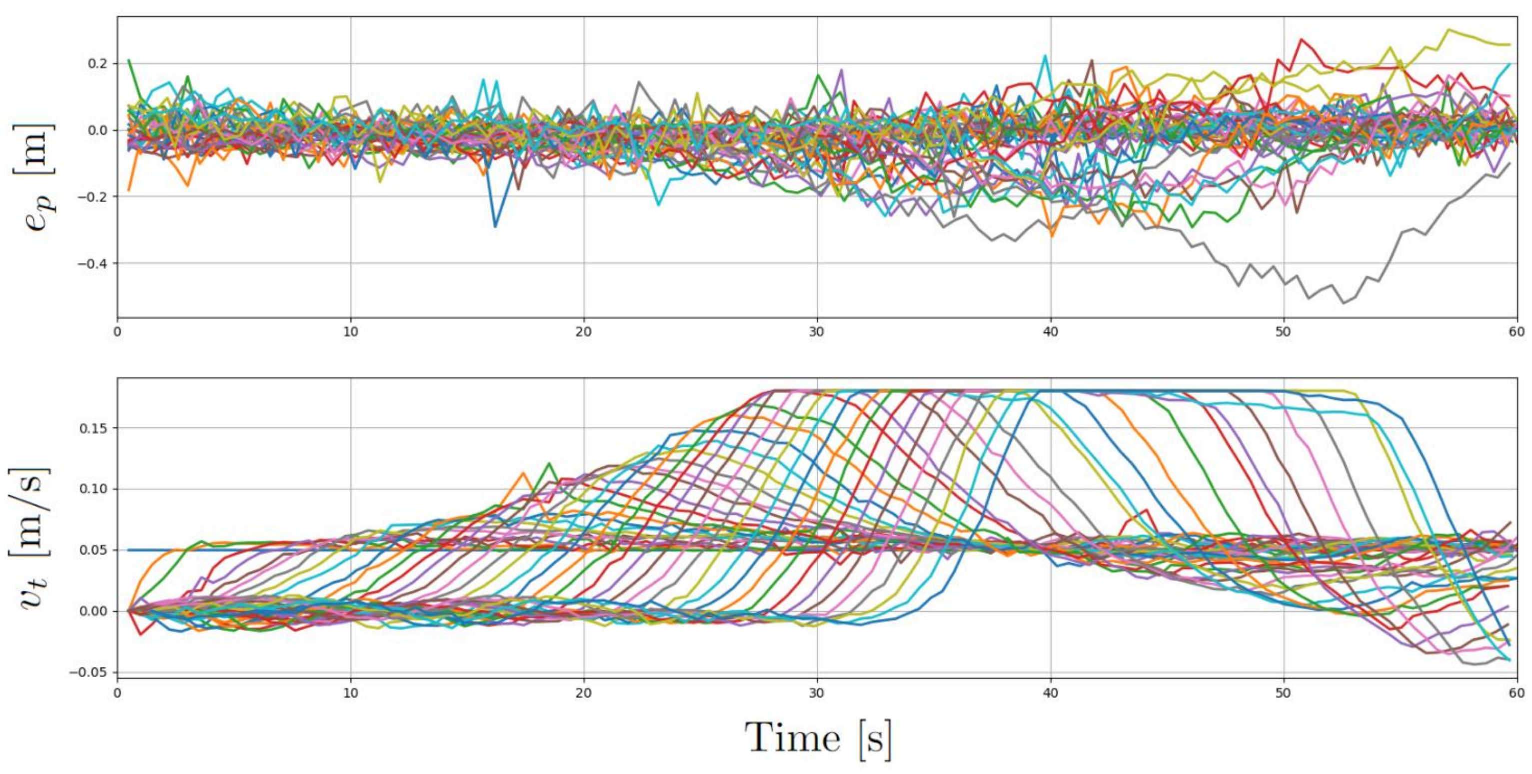

Figure 5: Transient response with *conventional* consensus approach

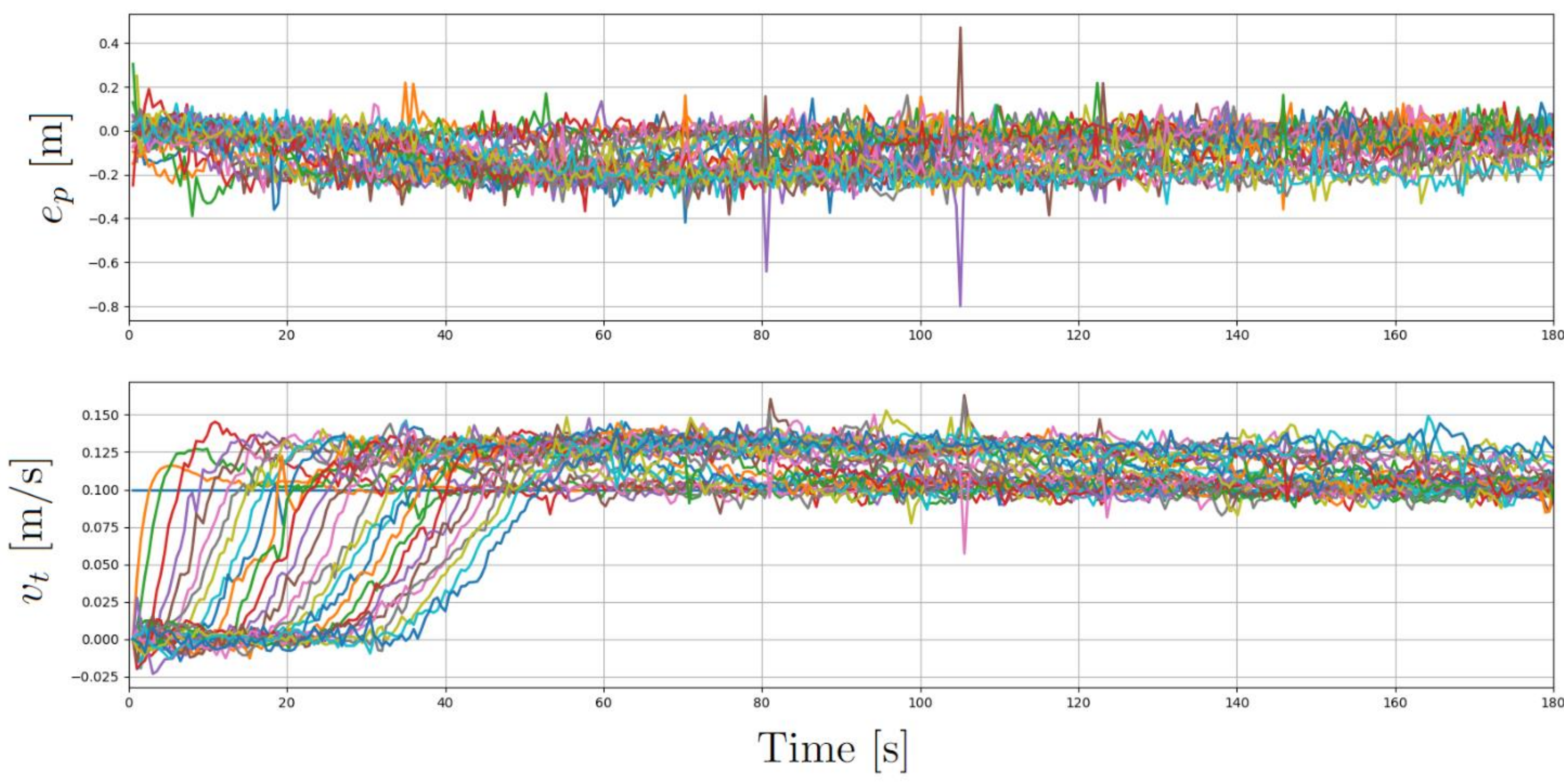

Figure 6: Transient response with *serial* consensus approach

References

[1] Tegling E., Bamieh B., Sandberg H. (2023). *Scale fragilities in localized consensus dynamics,* Automatica, 153, 111046.
[2] J. Hansson and E. Tegling *A closed-loop design for scalable high-order consensus,* IEEE 62nd CDC, Singapore, 2023.
[3] J. Hansson and E. Tegling, *Transient Analysis and Control for Scalable Network Systems.* In Lic. Thesis, Lund, 2023, 47-66.