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Accident avoidance by active intervention for Intelligent Vehicles

The Continuous Support Approach in interactIVe

Mauro Da Lio

interactIVe Summer School

4-6 July, 2012

Agenda

- Co-Drivers.
  - Human sensory-motor strategies.
  - Understanding (grounding) human goals and motivations.
- Artificial Cognitive Architectures (State of the Art)
  - Sense-Think-Act (obsolete)
  - Behavioural (Perception-Action).
  - Layered architectures
  - Motor Imagery.
- SP4 Co-Driver implementation
  - Layers and architecture
    - Motor primitives
    - Manoeuvering Level
    - Goals/Motivations Level
- Conclusions

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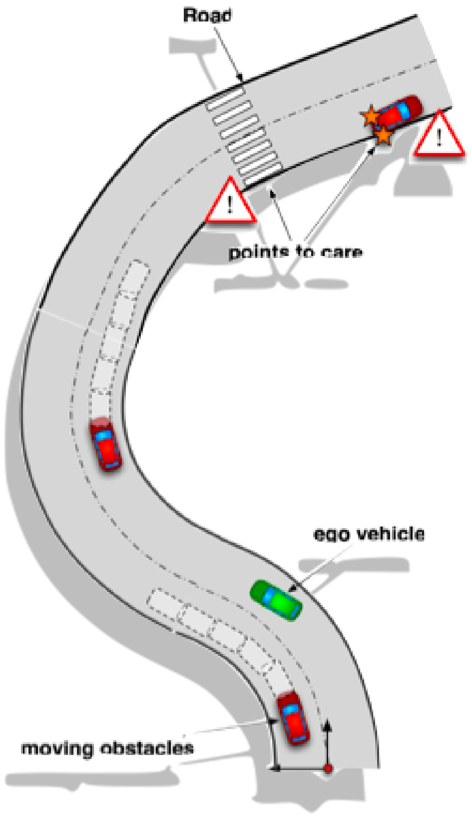
Artificial Co-Drivers

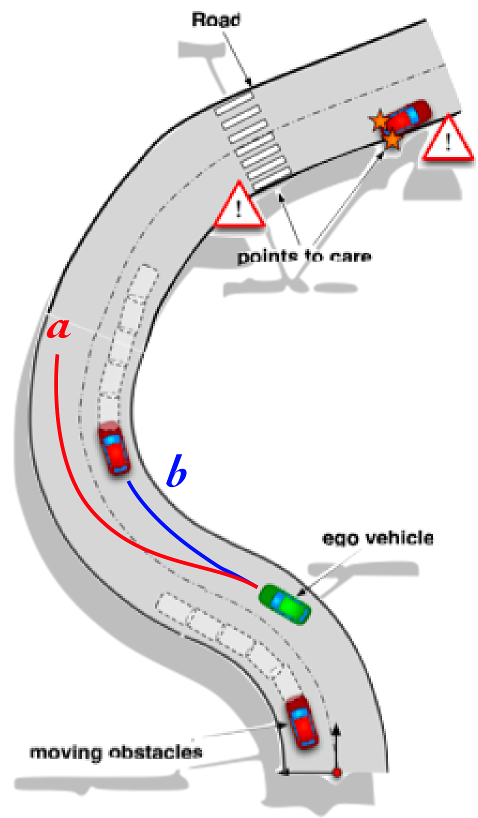


- How to provide holistic “Continuous Support”?

- “How would a human driver drive?”

- Let us make an **artificial driver**.
- (artificial driver as a “reference”)

Co-Driver must “understand” human driver



- How would a human drive?

- This question has multiple answers!
- Answer depend on some higher level motivations/goals.

- The co-driver must put himself “in the shoes” of the human driver and **understand the goal**.

The two main requirements /1

- Co-driver must **understand the goals of the human driver** (humans can do that with other humans, how do they do?)
  - Hurley, S.L., 2008. The shared circuits model (SCM): how control, mirroring, and simulation can enable imitation, deliberation, and mindreading. Behav. Brain Sci. 31, 1–58.
  - Grush, R. 2004. "The Emulation Theory of Representation: Motor Control, Imagery, and Perception." Behavioral and Brain Sciences 27 (3): 377-396.
  - Jeannerod, M. 2001. "Neural Simulation of Action: A Unifying Mechanism for Motor Cognition." NeuroImage 14 (1 II): S103-S109.
- "putting the co-driver in the shoes of the real driver" means the co-driver "emulates" the real driver such as **in covert motor activities**.
- **Link driver behaviour to meaningful goals** (understand driver goals/motivations).

The two main requirements /2

- Co-driver must be:
- **Humanlike**. Reproduce human sensory-motor strategies (path planning and motor patterns just like a human).
  - D Liu, E. Todorov, Evidence for the Flexible Sensorimotor Strategies Predicted by **Optimal** Feedback **Control**, Journal of Neuroscience, 2007 • 27(35):9354 –9368
  - P. Viviani, T. Flash, **Minimum-jerk**, two-thirds power law, and isochrony: converging approaches to movement planning. J Exp Psychol 21: 32-53, 1995.
  - “Even if skilled performance on a certain task is not exactly optimal, but is just ‘good enough’, it has been made good enough by processes whose limit is optimality”.
- Human motor patterns respond to **optimality criteria** and may be reproduced by Receding Horizon Optimal Control.

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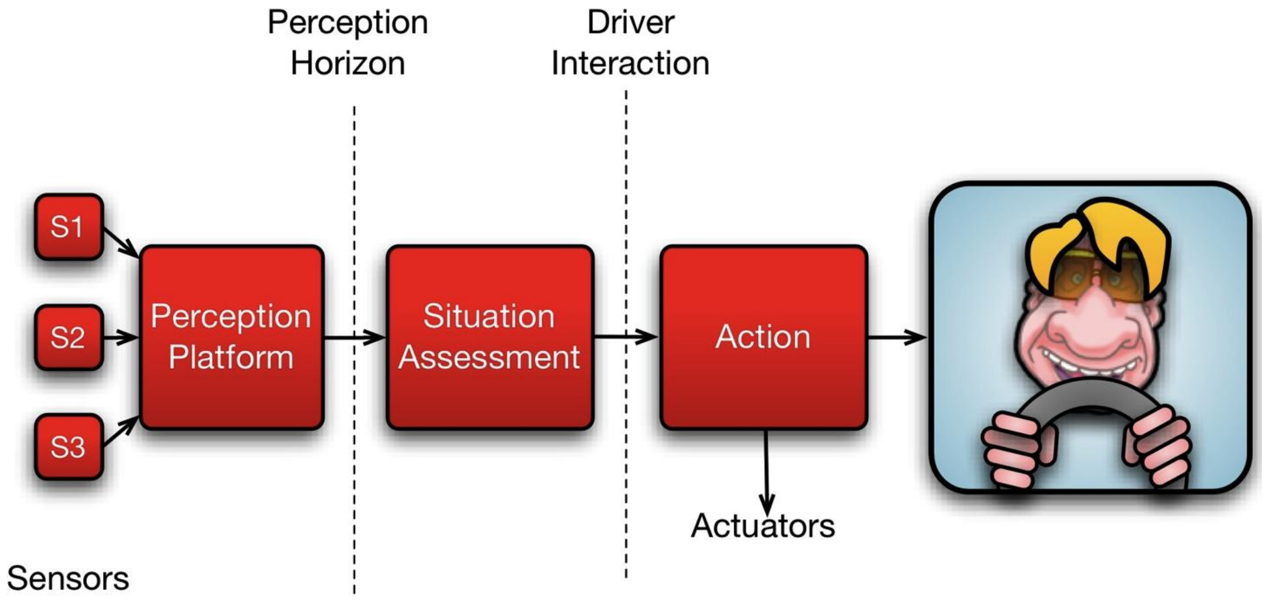
Architecture: The traditional sense-think-act paradigm of AI

- The central idea is the existence of an “internal model of the world”.
- **Problems**: perception “per se”; not scalable (interfaces are choke points); difficult to test; is not what happens in the human brain; not fault tolerant; hard to conceal with motor imagery and covert sensory-motor activity.



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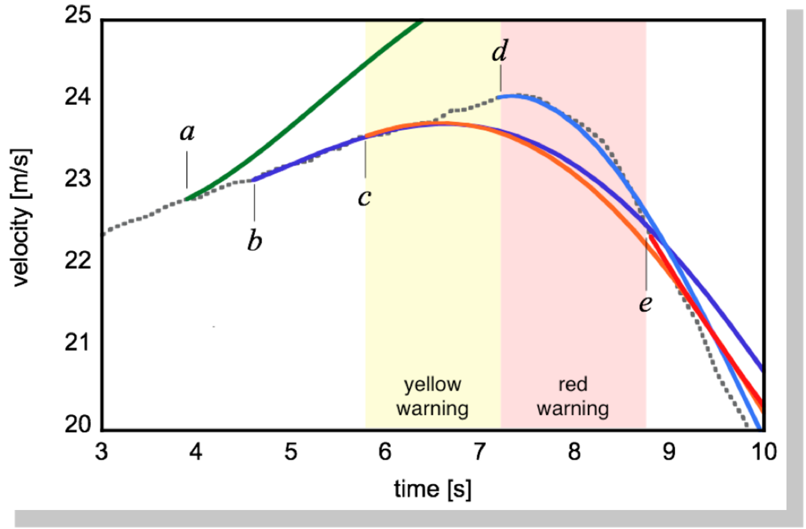
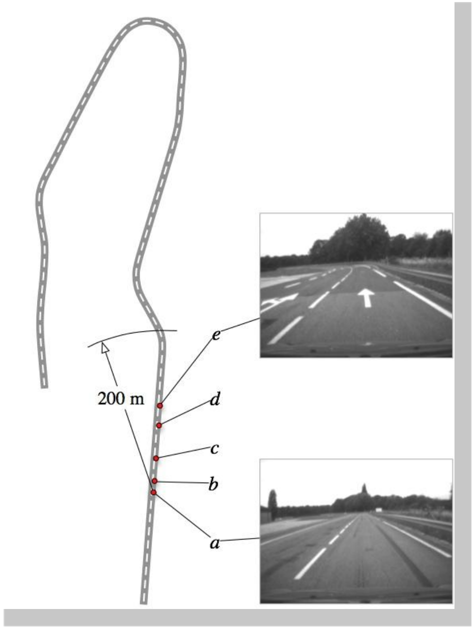
Sense-think-act success story/1

- A **tutor** made of a one-level virtual driver (called **“reference maneuver”**) was built into SASPENCE and INSAFES (+ evasive maneuver).
- **Limitation**: missing motor imagery it was not able to “understand” the driver goal (giving recommendation for a pre-defined goal).
  - Da Lio, Biral et. al, T-ITS, 2010 (2 papers)





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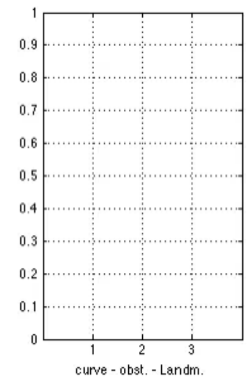
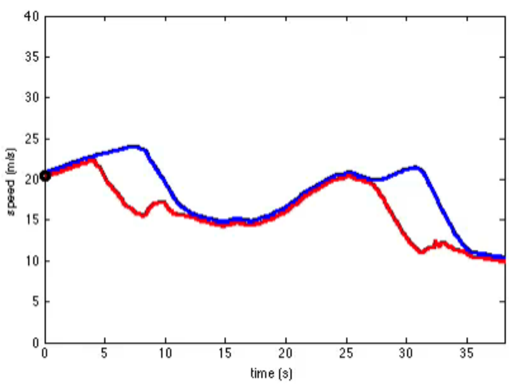
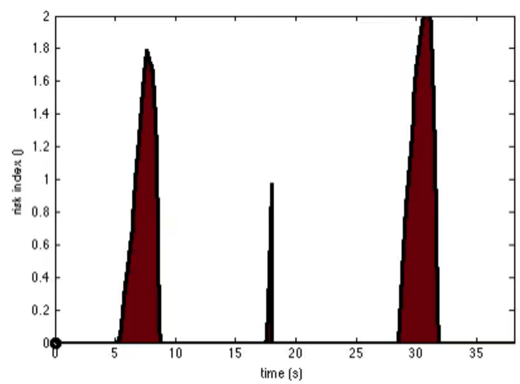
Sense-think-act success story/1

(Versailles test track: reference manovre (red) vs. real driver (blue) movie)



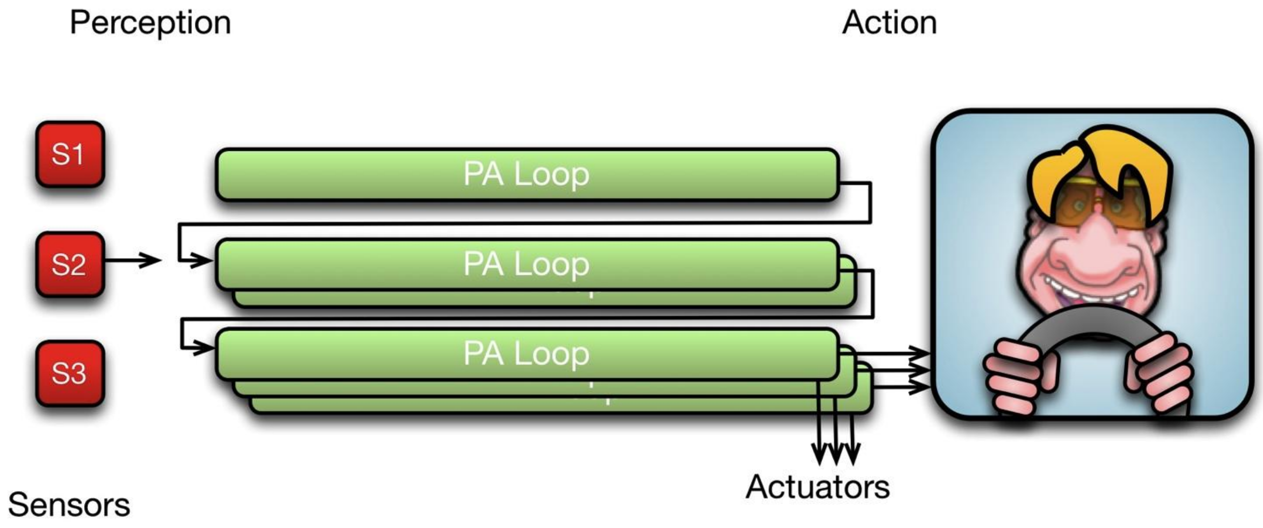




Architecture: The behavioural model

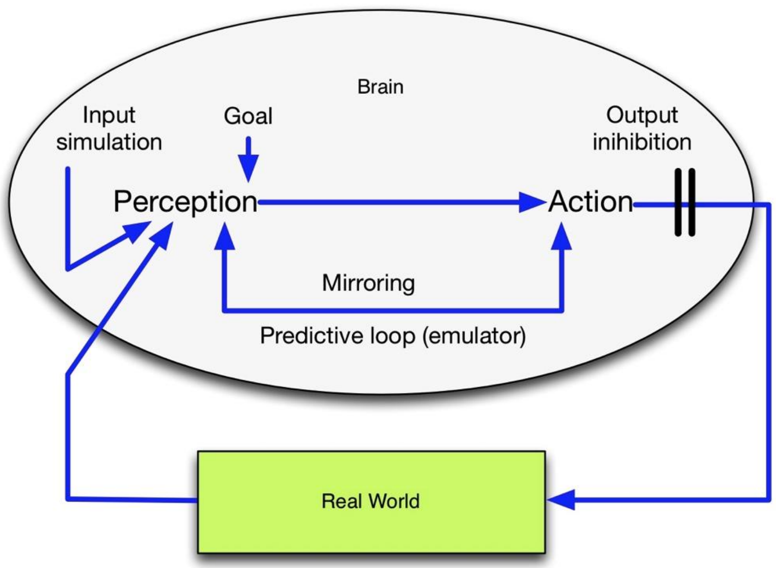
- Decomposition in parallel behaviours (hierarchical levels of competence).
- Is based on Perception-Action cycles (no internal model of the world).
- Multi-goal, multi-sensor (perceptual synthesis), robust, scalable, subsumptive, each level includes sub-level competences.

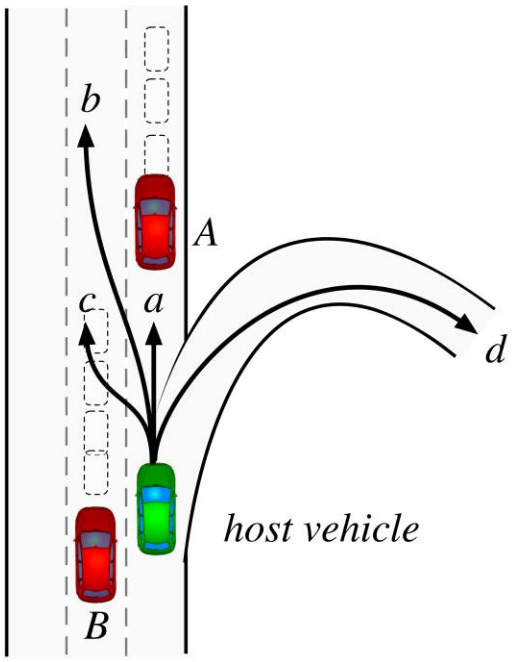
  - R. A. Brooks. A robust layered control system for a mobile robot. IEEE Journal of Robotics and Automation, 14(23), April 1986.



Theory of Cognition by means of emulation.

- **“Thinking” is simulated interaction.**
- Emulation theory of cognition **(**Grush, Hurley, Jannerod, et al.) enables **imitation**, **motor imagery**, deliberation, mindreading, understanding….





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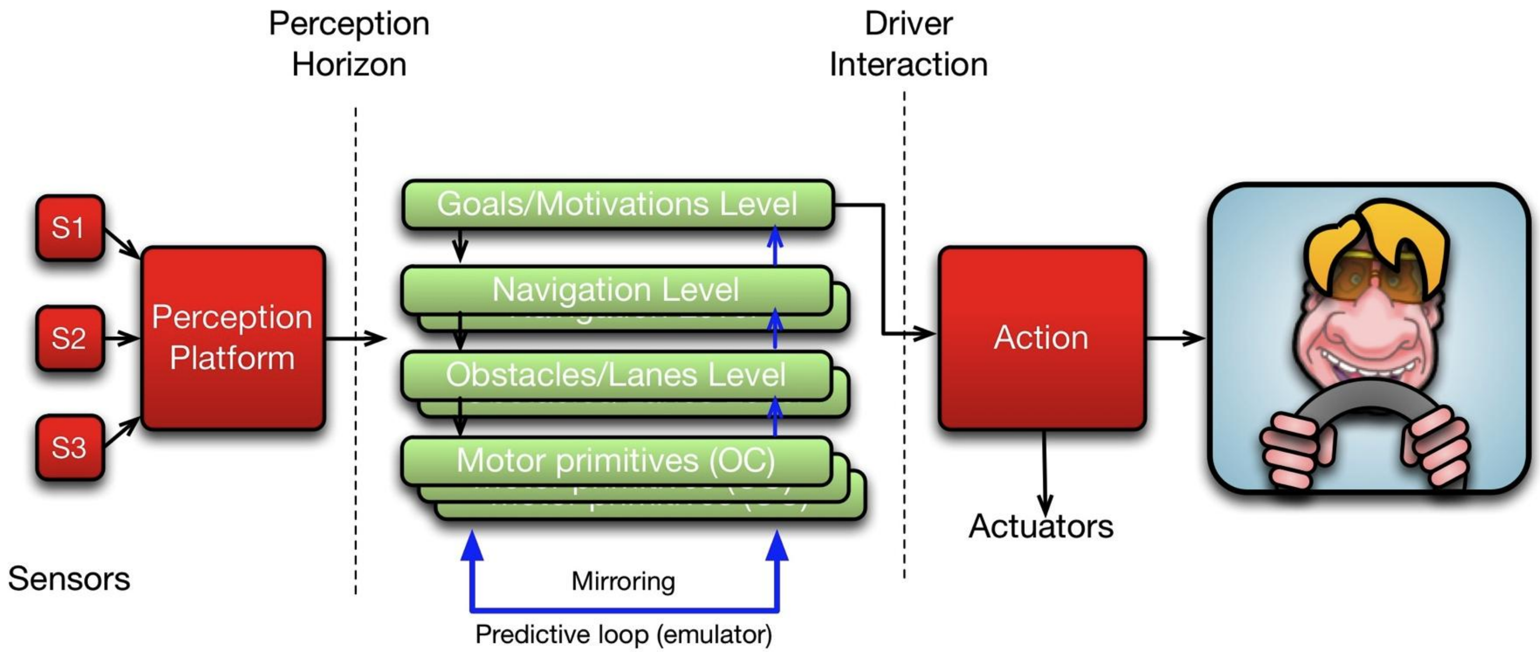
The Co-Driver of SP4

- Four layers ECOM-like behavioural subsumptive architecture.
- Forward/mirroring mechanisms (by Optimal Control).
- Motor imagery, **inference of driver's goals**.



Lowest level (motor primitives)

- Motor primitives are based on parametric Optimal Control sensory-motor loops.
- Minimum jerk with parametric minimum time term.

  - Achieve specified longitudinal uniform motion (parametric)
  - Achieve free longitudinal uniform motion (parametric)

  - Align with specified direction of travel (parametric)
  - Shift laterally (parametric)
  - *Achieve specified trajectory* (not implemented yet)

  - ….

  - Extendable architecture!

Longitudinal motor primitives

- Move from current state (speed, acceleration) to a desired state (below)

$$x(0) = 0, \quad u(0) = U, \quad a(0) = A$$

- while using the following humanlike criterion:

$$\min \int_0^T (jp(t)^2 + wT)\,dt$$

- *i.e.*, a trade-off between minimum jerk and minimum time.
  - For specified longitudinal uniform motion $x(t) = s_0 + v_0(t - \tau)$

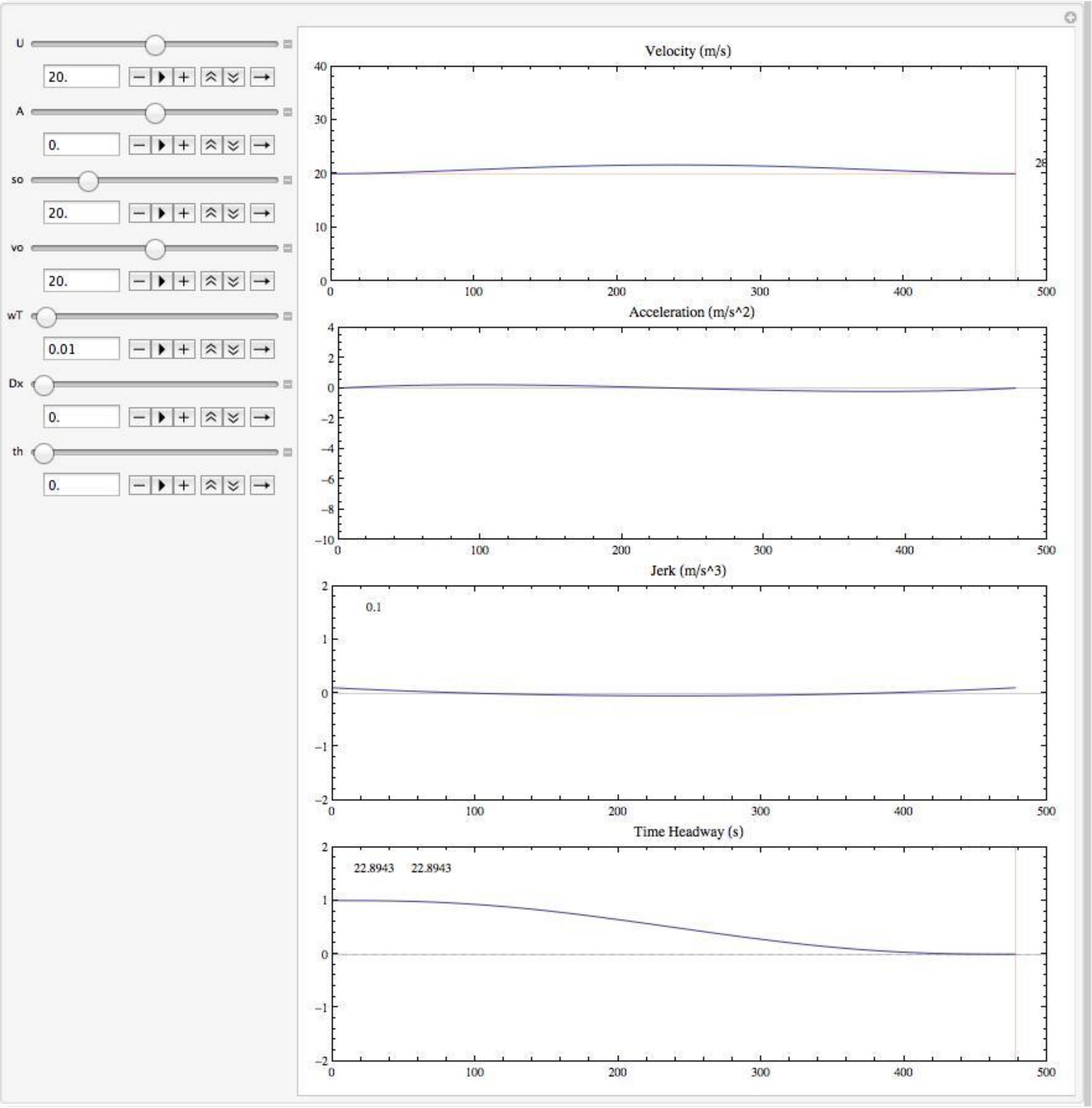
$$x(T) = s_0 + v_0(T - \tau), \quad u(T) = v_0, \quad a(T) = 0$$

  - For free longitudinal uniform motion (parametric)

$$x(T) = free, \quad u(T) = free, \quad a(T) = 0$$

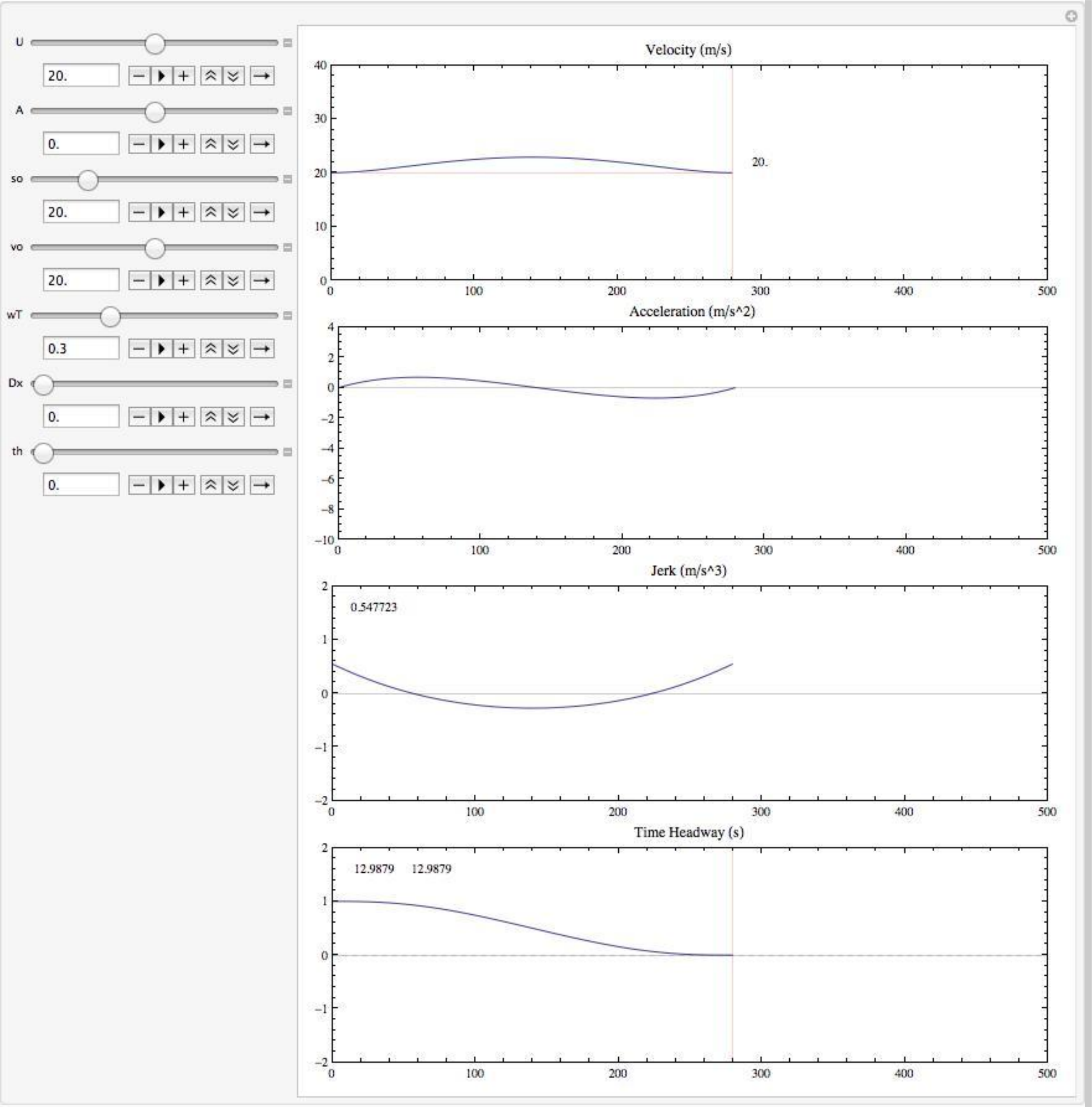
Example

- Close 20 m gap



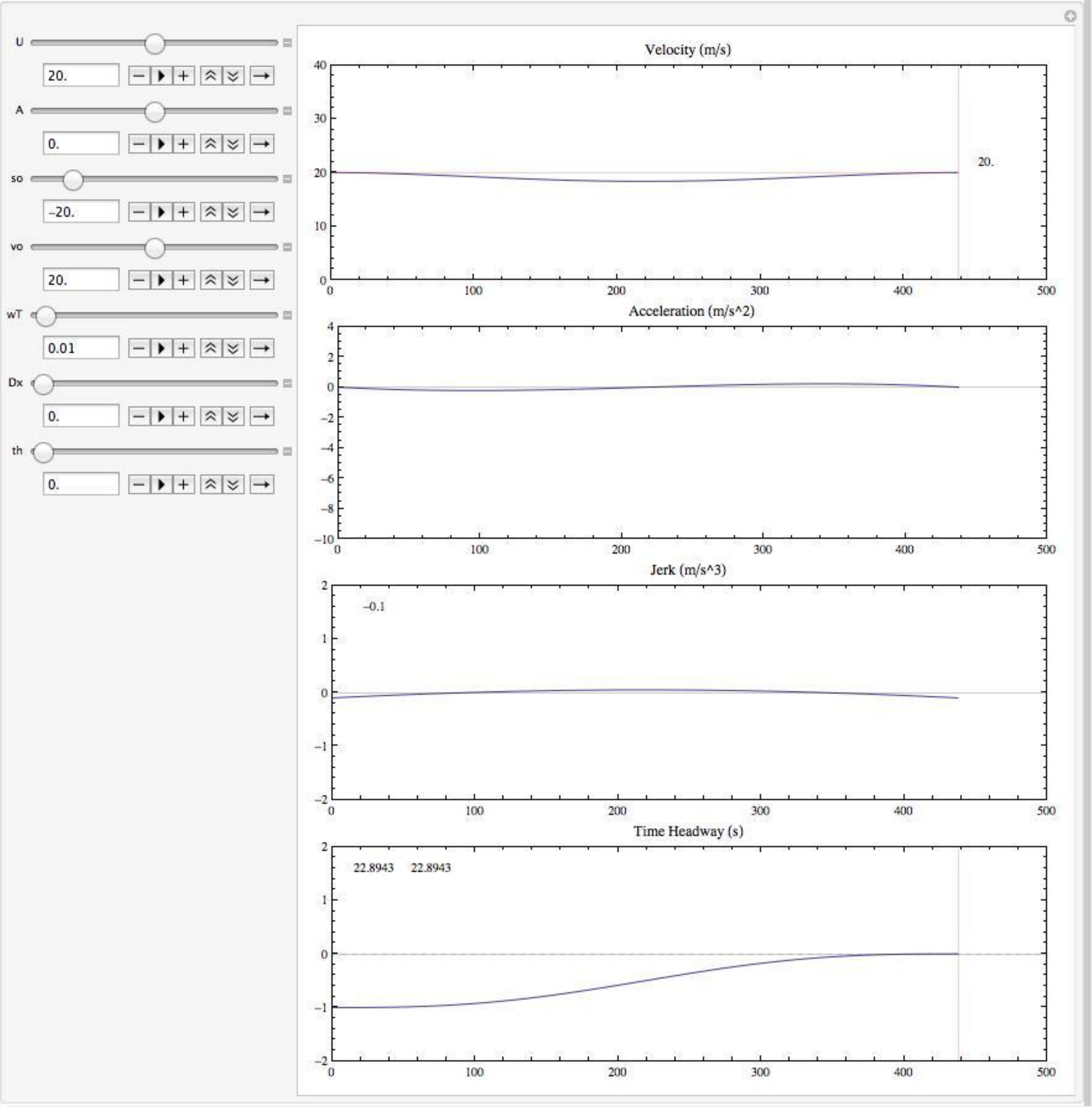
Example

- Close 20 m gap faster



Example

- Open 20 m gap



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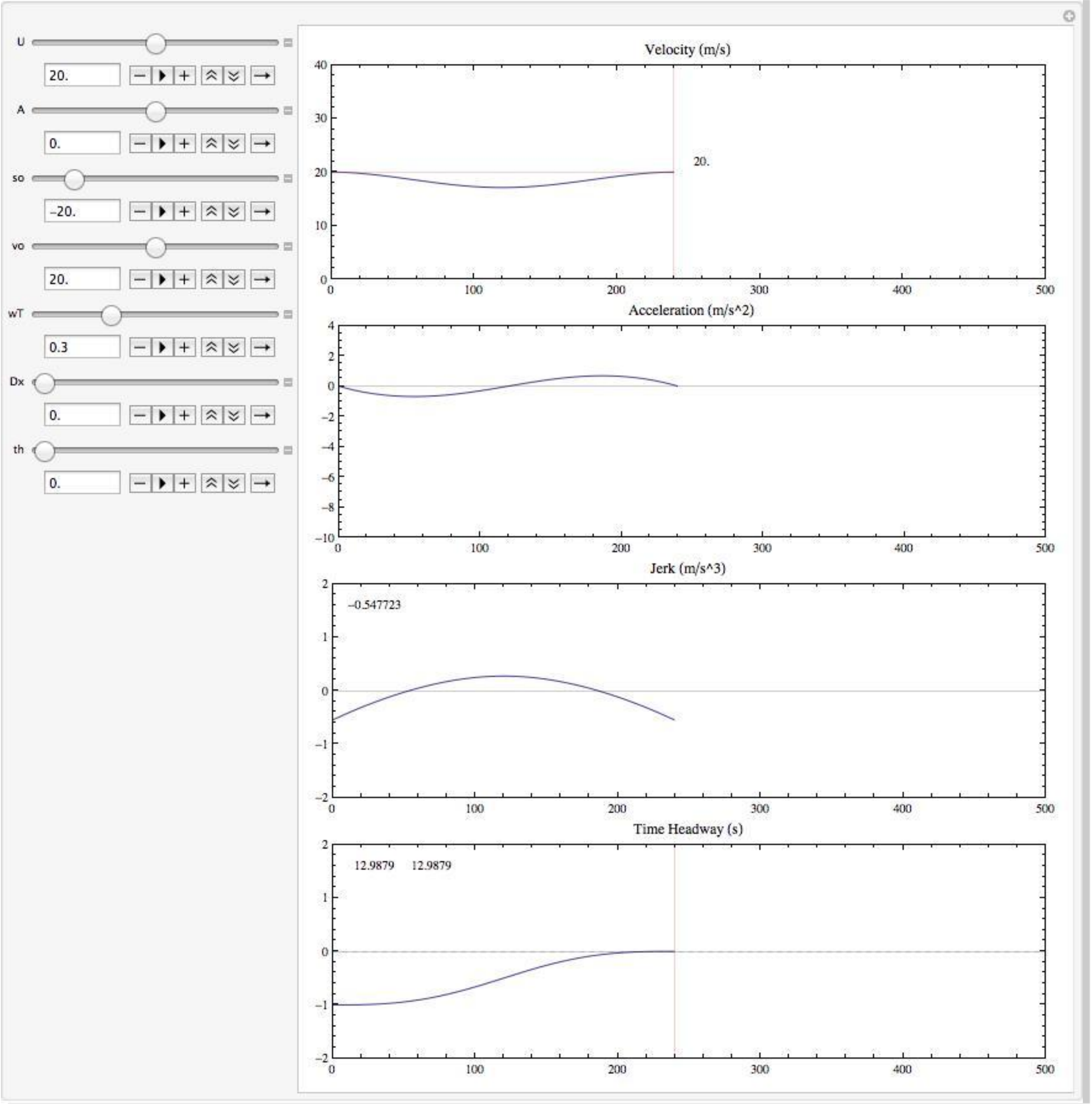
Example

- Open 20 m gap faster



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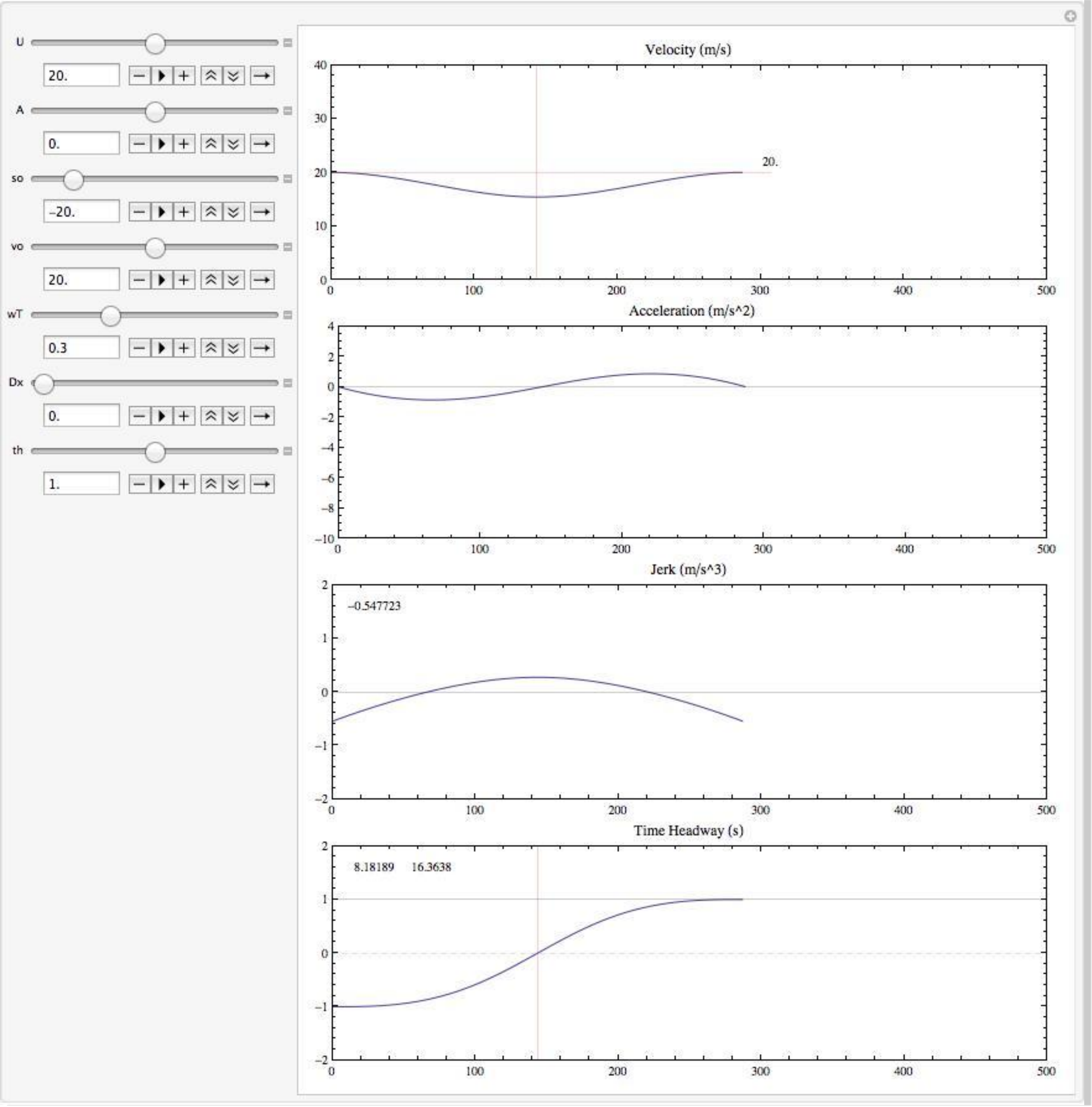
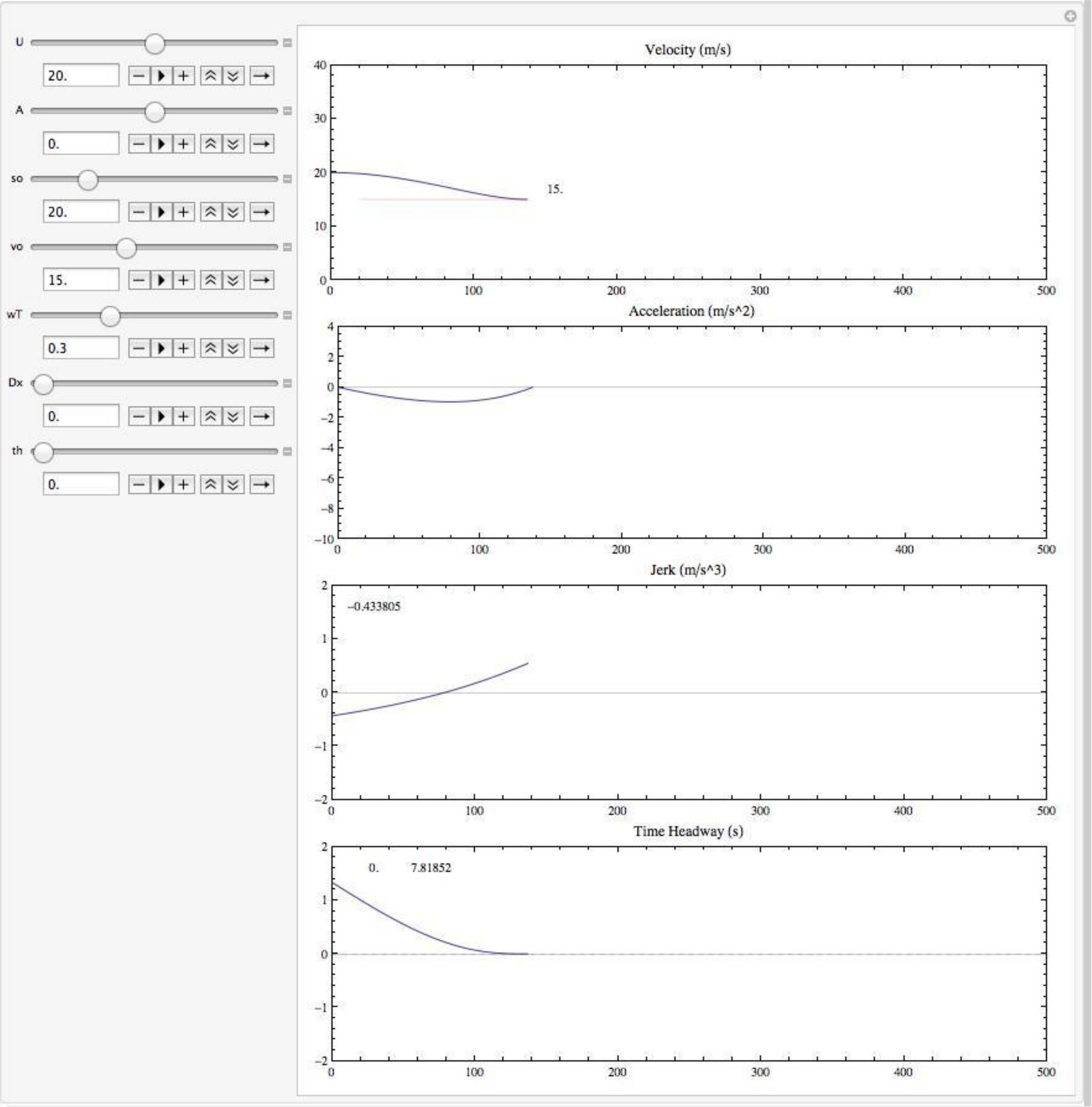
Example

- Open 20 m gap faster
  with 1 s headway



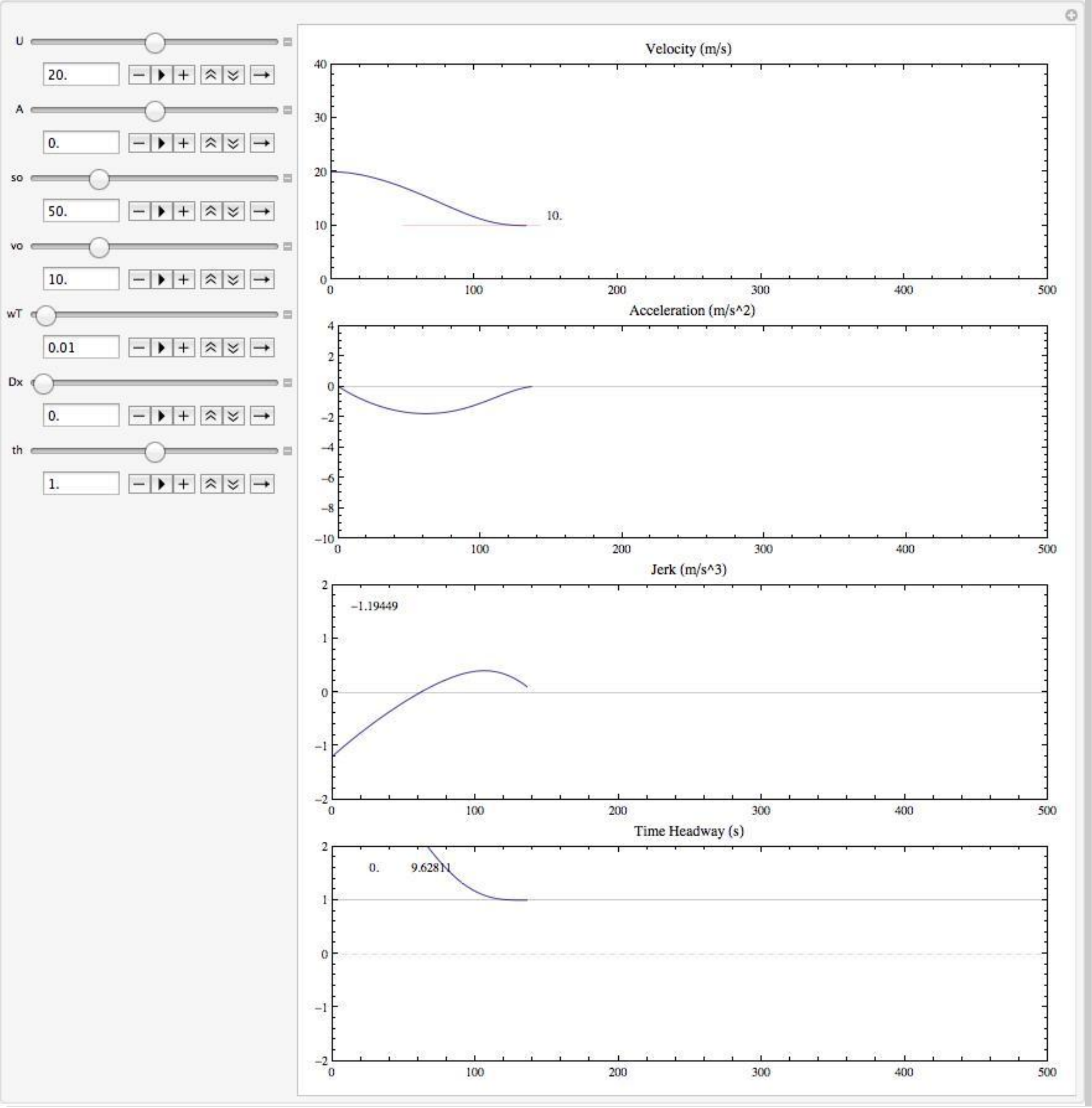
Example

- Reduce speed to 15 m/s



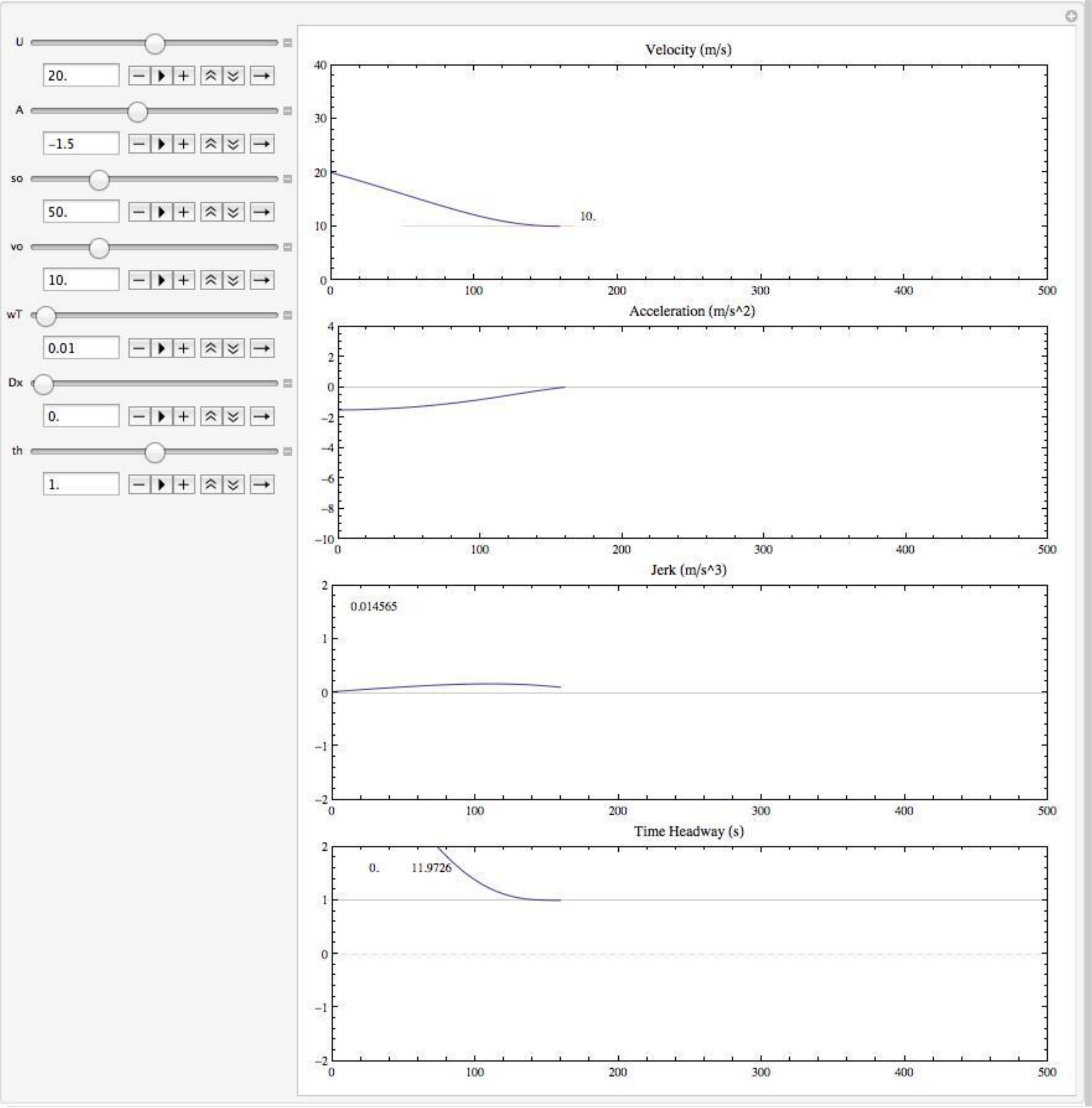
Example

- Reduce speed to 10 m/s
  with 1 s headway



Example

- Reduce speed to 10 m/s
  with 1 s headway
  with -1.5 m/s^2 initial acceleration



Second level (handling single obstacle and lanes)

- Motor primitives are based on parametric Optimal Control sensory-motor loops.
- Minimum jerk with parametric minimum time term.

  - Free Flow (achieve uniform speed, > 0, in some time T, *)
  - Lane Handling (align with lane or change lane in some time T)
  - … *(curve approaching)*

  - Clear Object (pass on either side, subject to minimum lateral jerk)
  - Follow Object (queue object at specified time headway. *)
  - …. (*curve negotiation, intersection negotiation,…*)

  - (*) subject to minimum jerk/minimum time trade-off.

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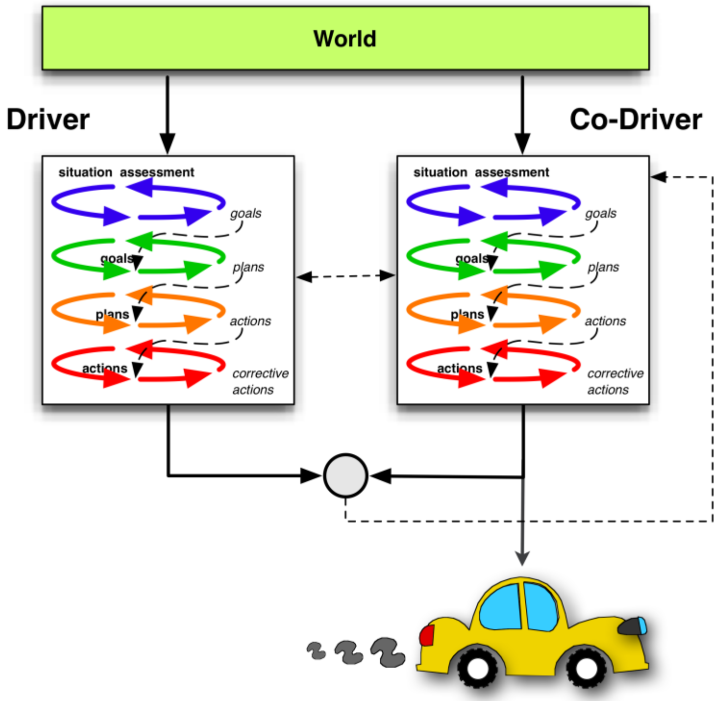
Third level (navigation level)

- Combination of motor primitives that makes a meaningful **navigation** between lanes and obstacles (finding navigable strips).

  - In-Lane
    - Navigate in-lane, following front objects and clearing the others, *managing curve approaching, …,* .
  - Extended-Lane (partially using adjacent lane)
    - Navigate loosely in-lane, clearing most of the objects, *managing curve approaching, …,* .
  - Lane change
    - Navigate to next lane, clearing most of the objects, while following selected others, *managing curve approaching, …,* .
  - … (Bifurcation)

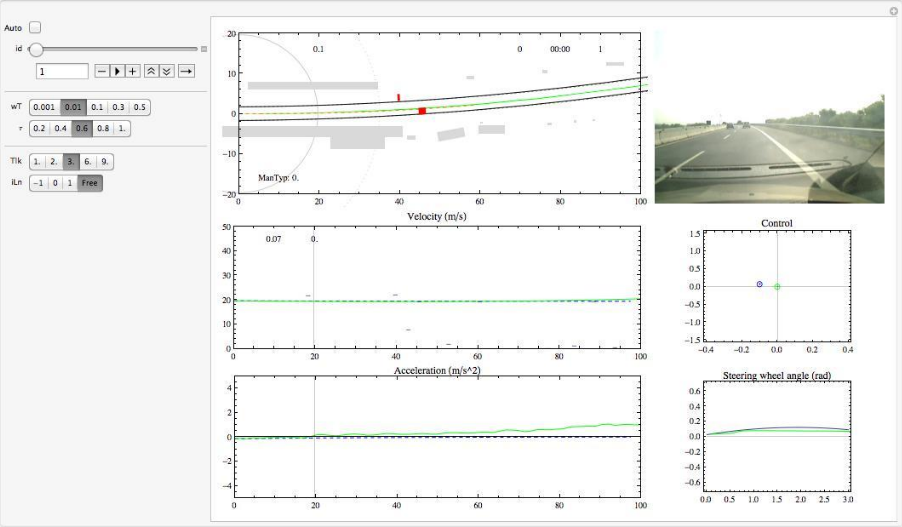
Top level (goal/motivations level)

- Inference of driver intentions (model identification problem).
- Implements motor imagery, imitation, mindreading (model identification) for all meaningful goal.



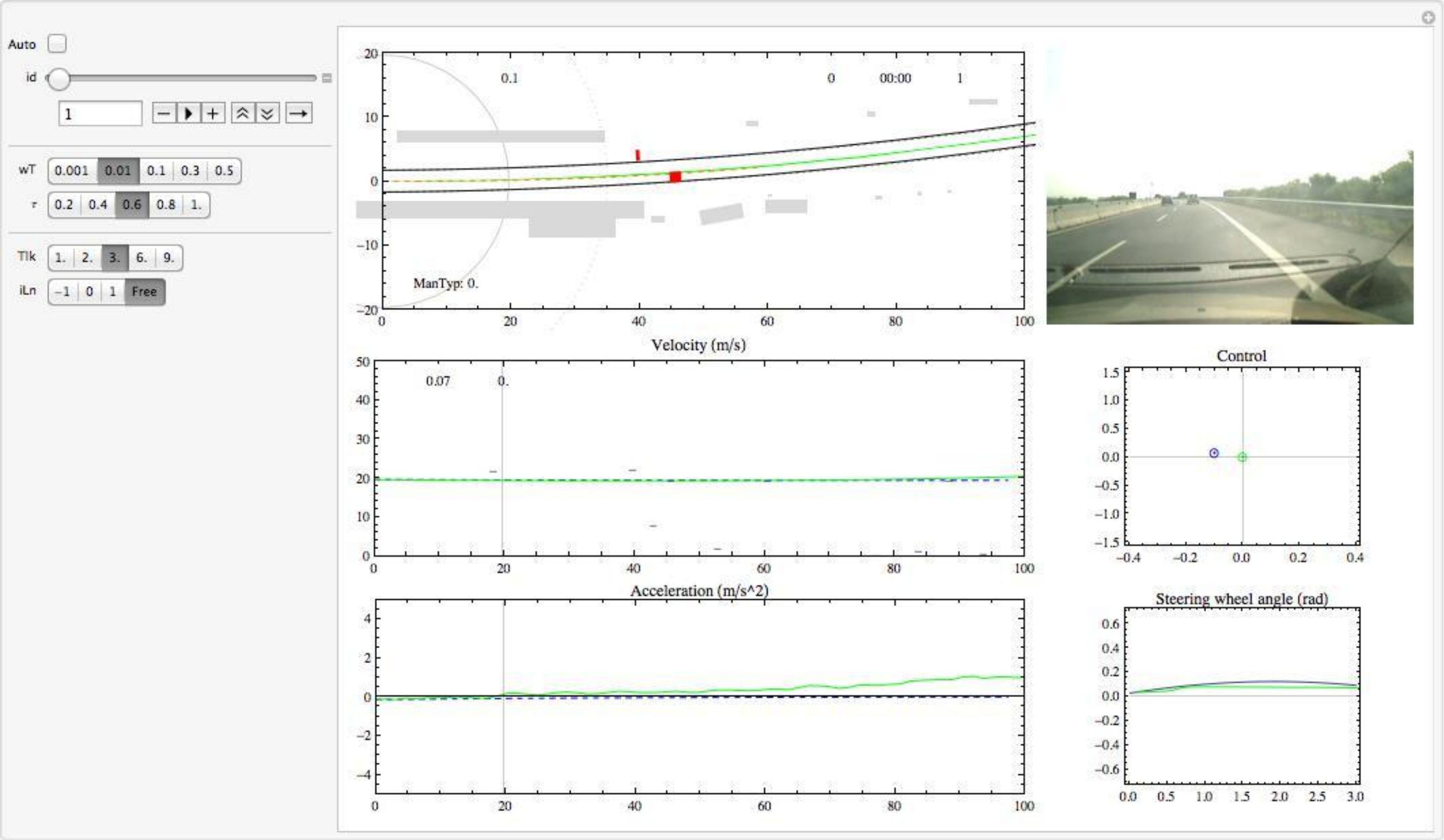
How does it work?

- This interface allows to subsume several goals (left pane) of the 4 layers as if we were a fifth layer.
- Green is the actual driver. Blue and Red is motor imagery (blue ignores obstacles).
- The system uses only a laser scanner and camera lane recognition.
- Panes represent the bird view, speed, acceleration, camera, longitudinal and lateral control, and steering wheel.



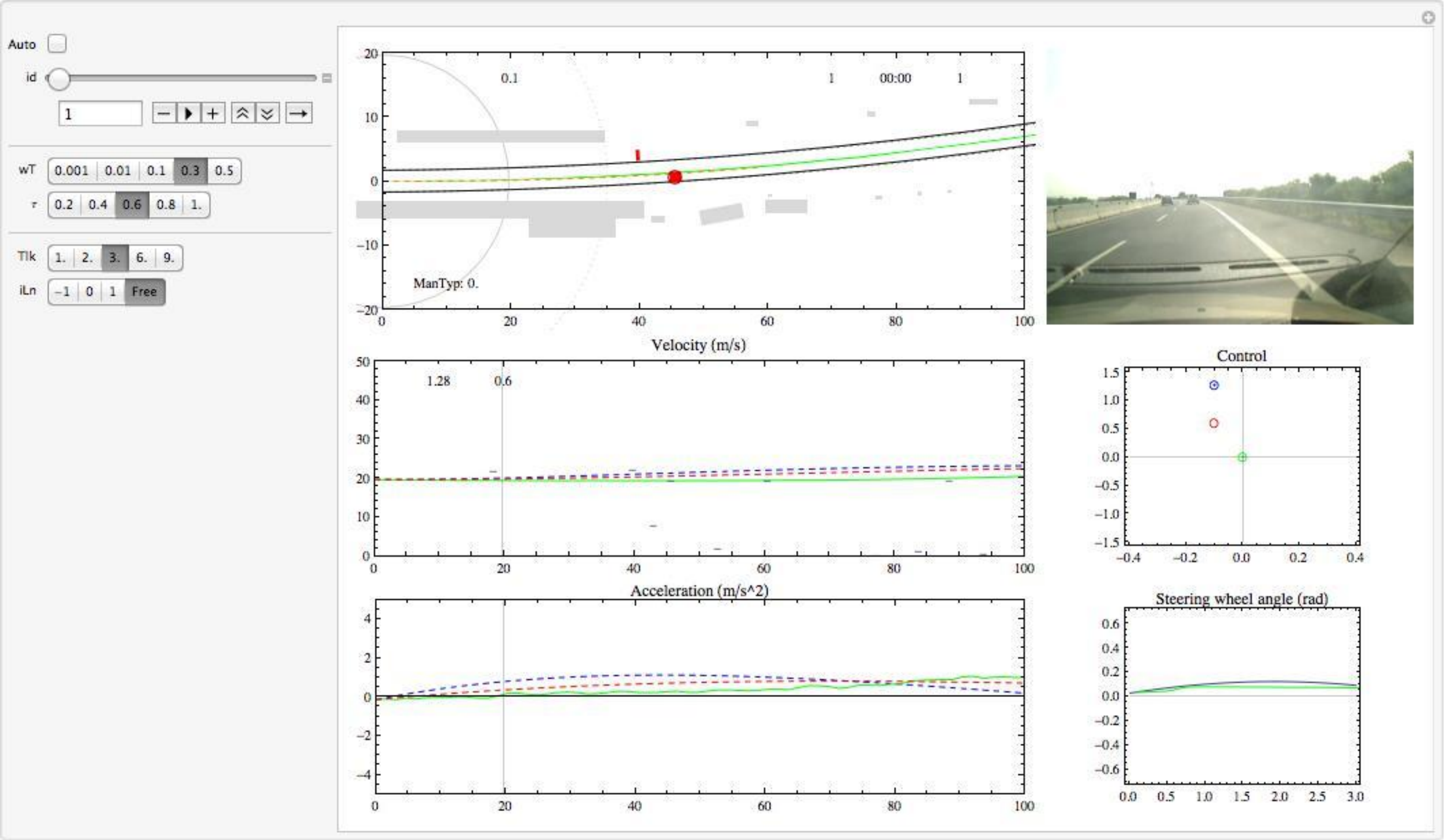
Frame 1

- “standard” settings for the ECOM states.



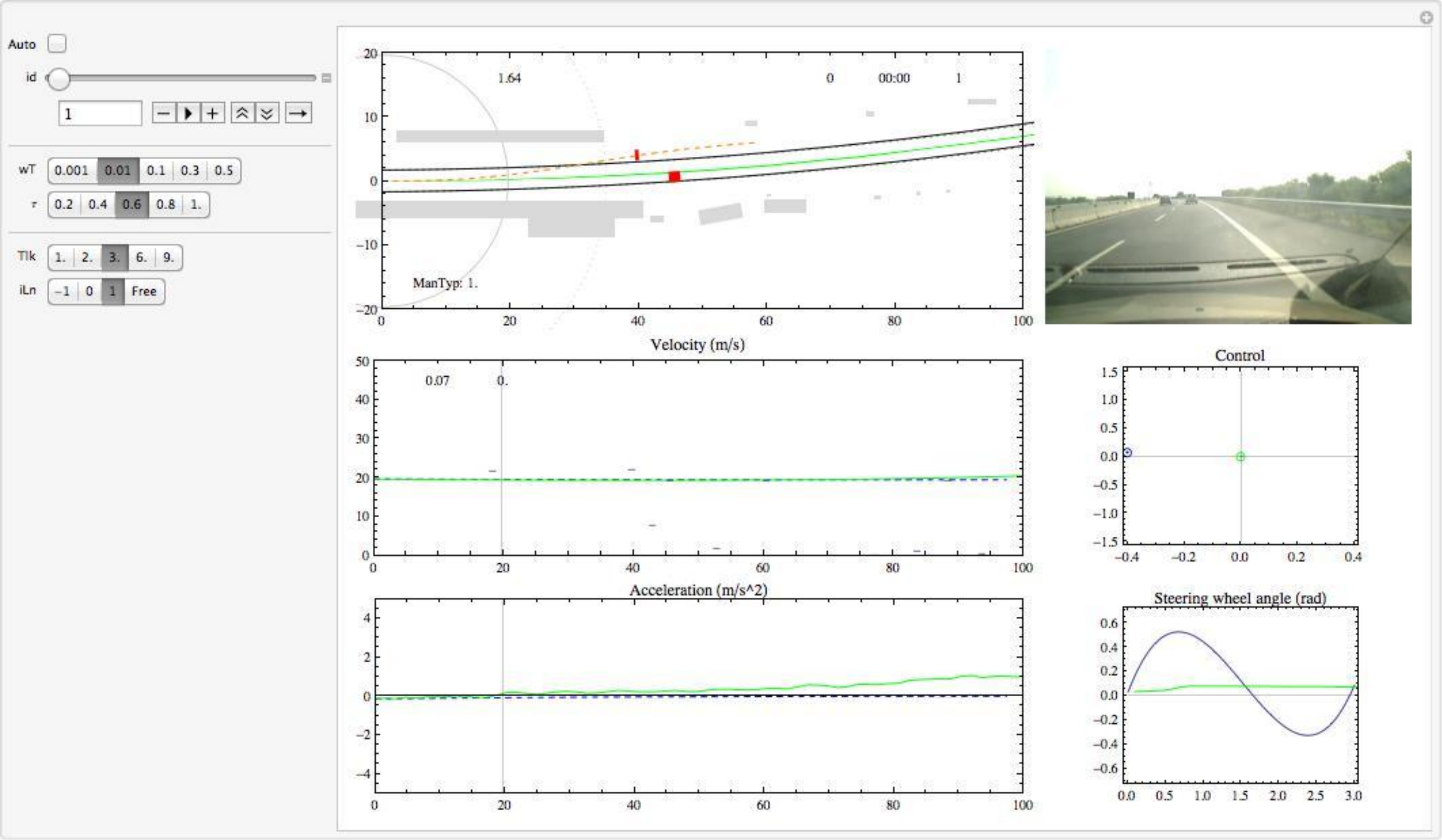
Frame 1

- “faster” (wT = 0.3). Note how different the control would be, and obstacle.



Frame 1

- Motor imagery for lane change.



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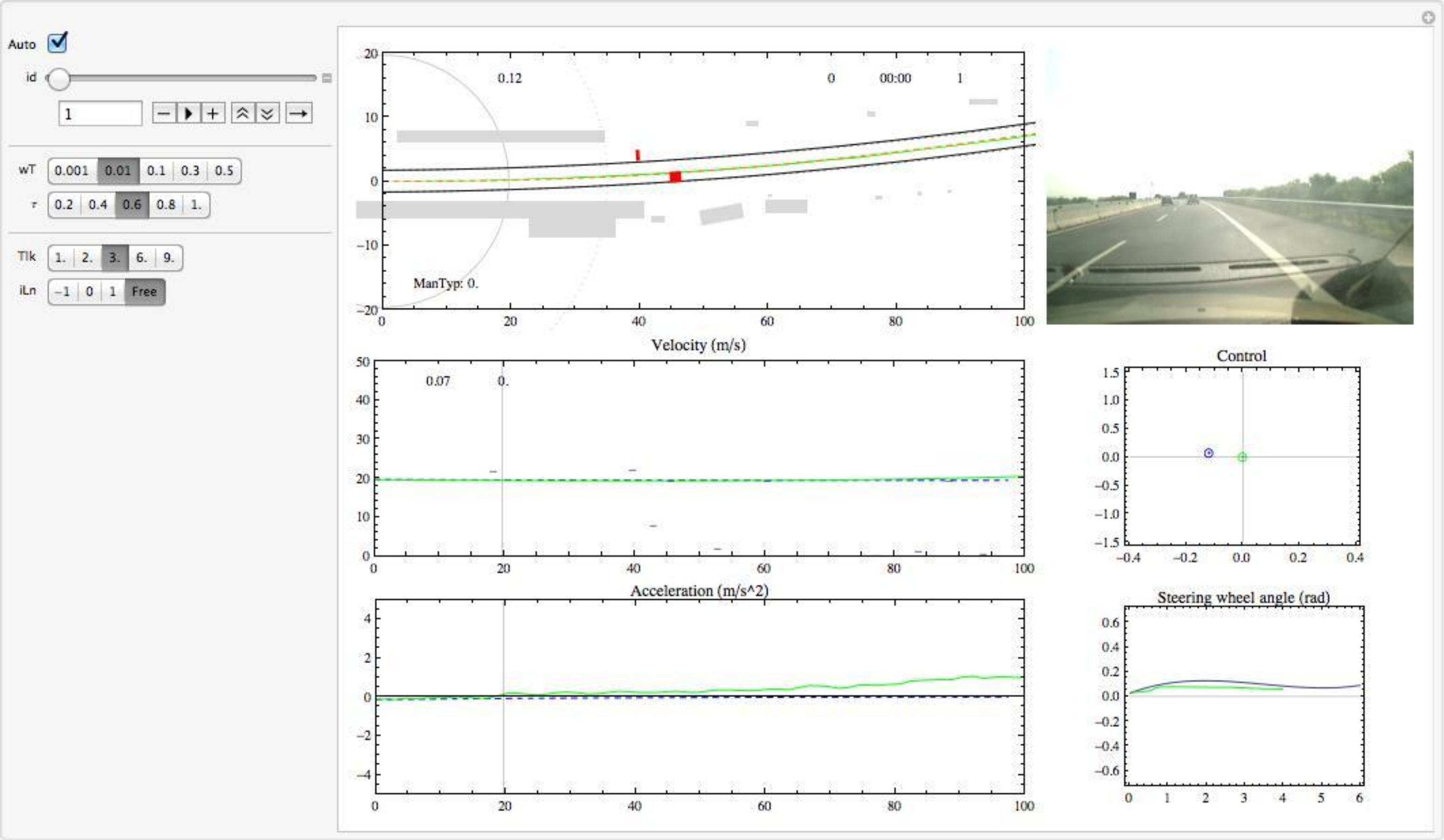
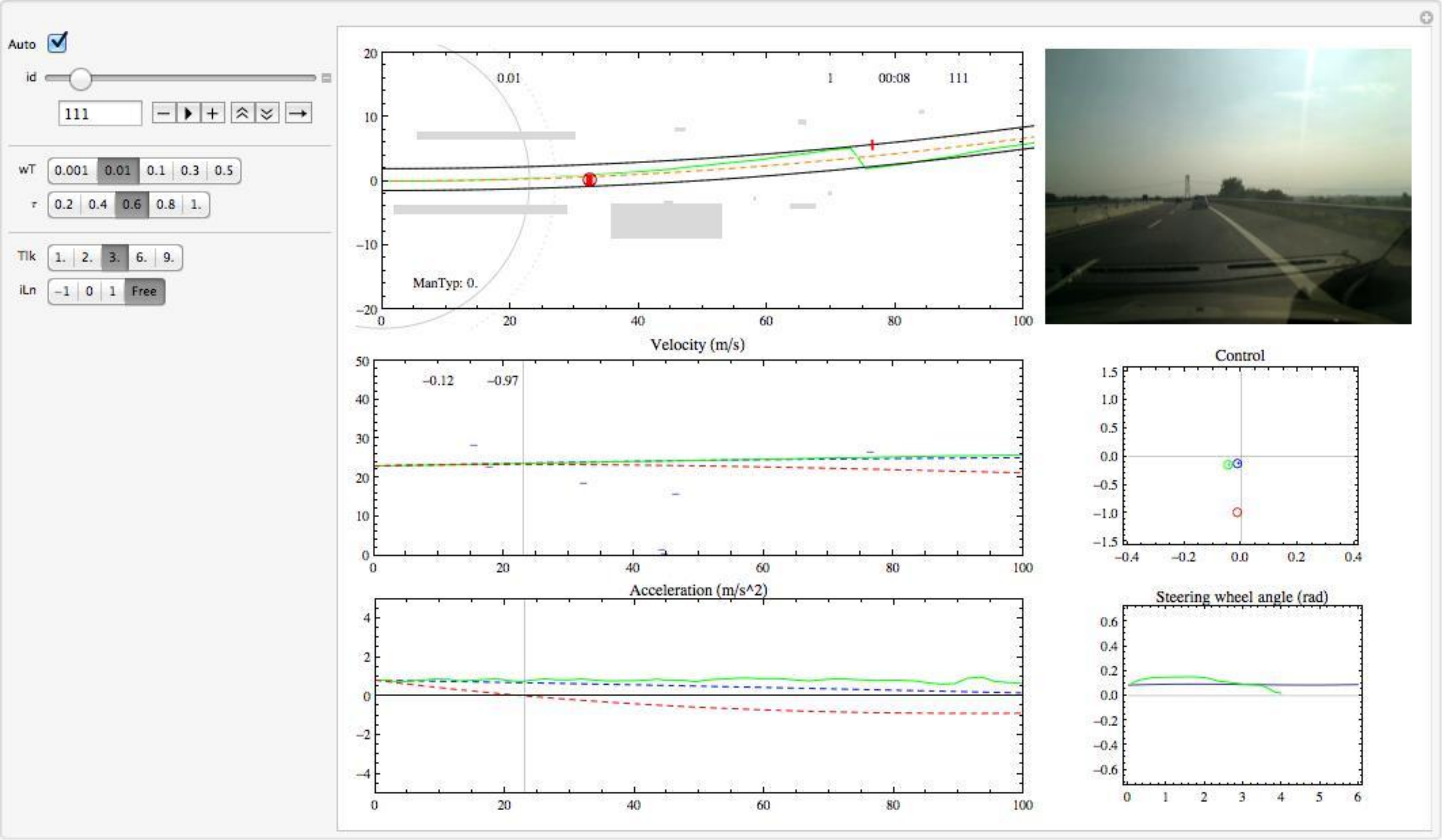
Frame 1

- Inference of driver goals (auto checkbox on)



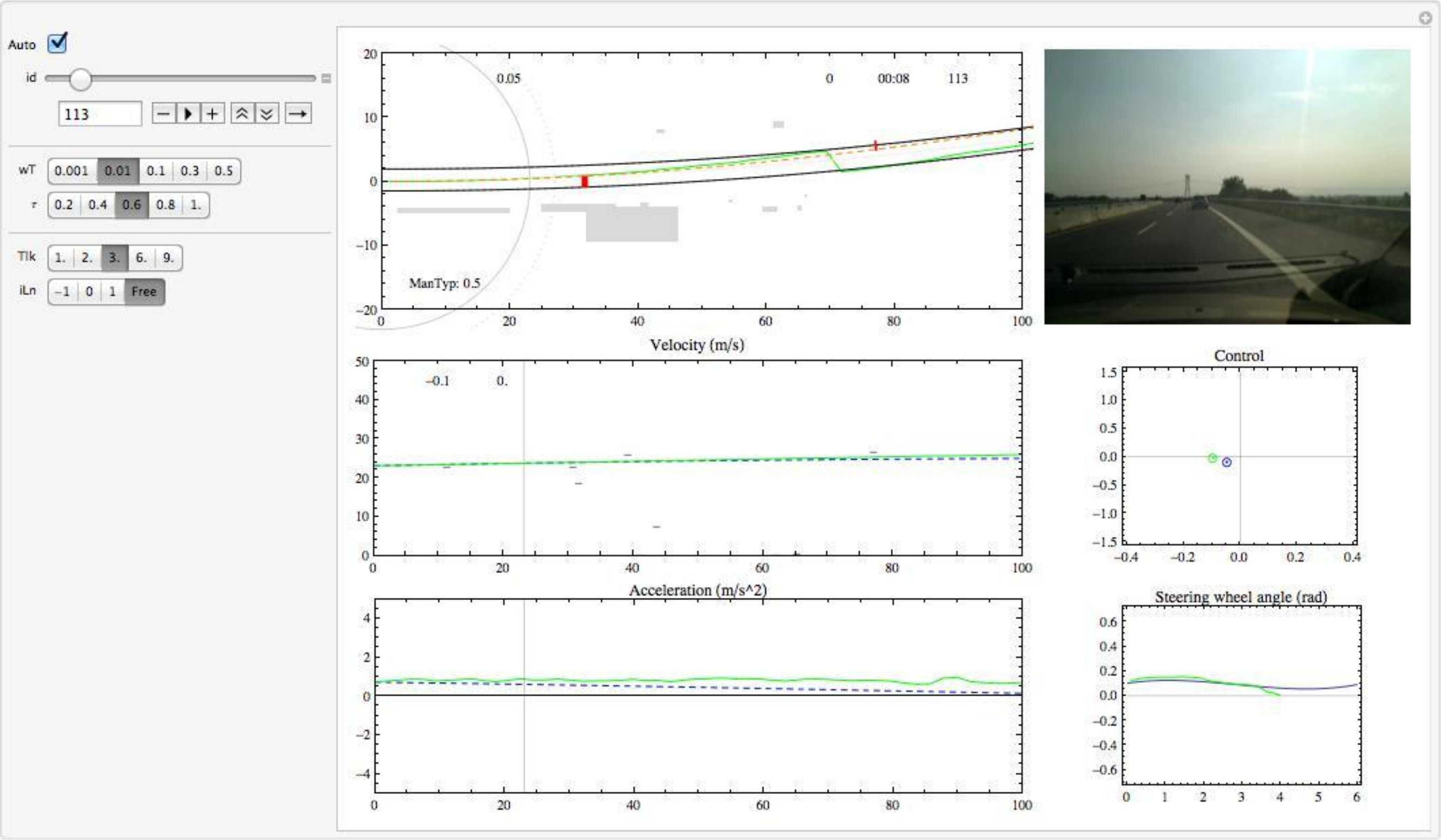
Frame 111

- Last frame before lane change. Obstacle in front (not dangerous).



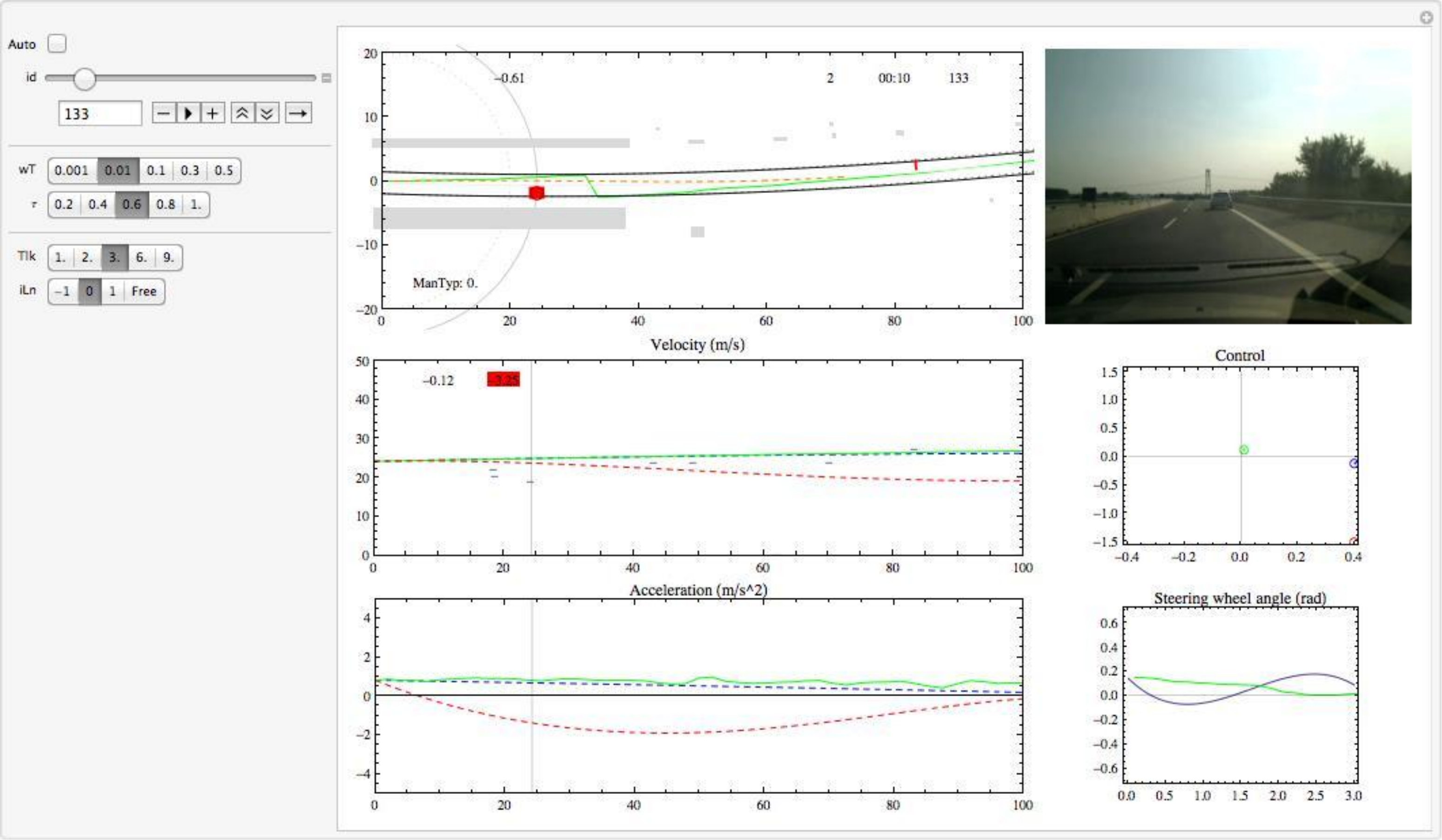
Frame 113

- Co-driver detects lane change. Steering activity match. No obstacle.



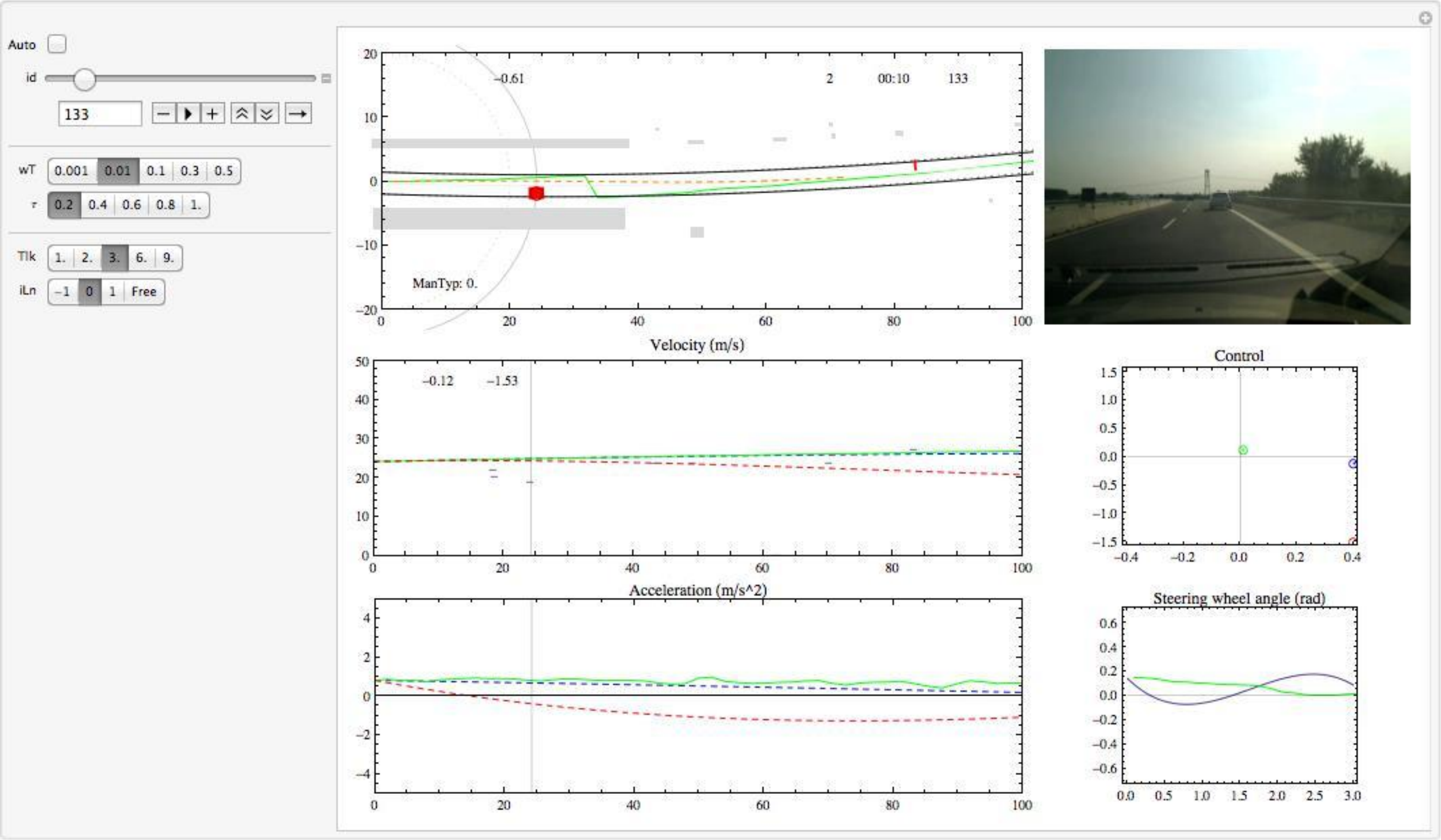
Frame 133

- (Manual). What if the vehicle were to return in its lane?



Frame 133

- Could keep 0.2 s time headway!



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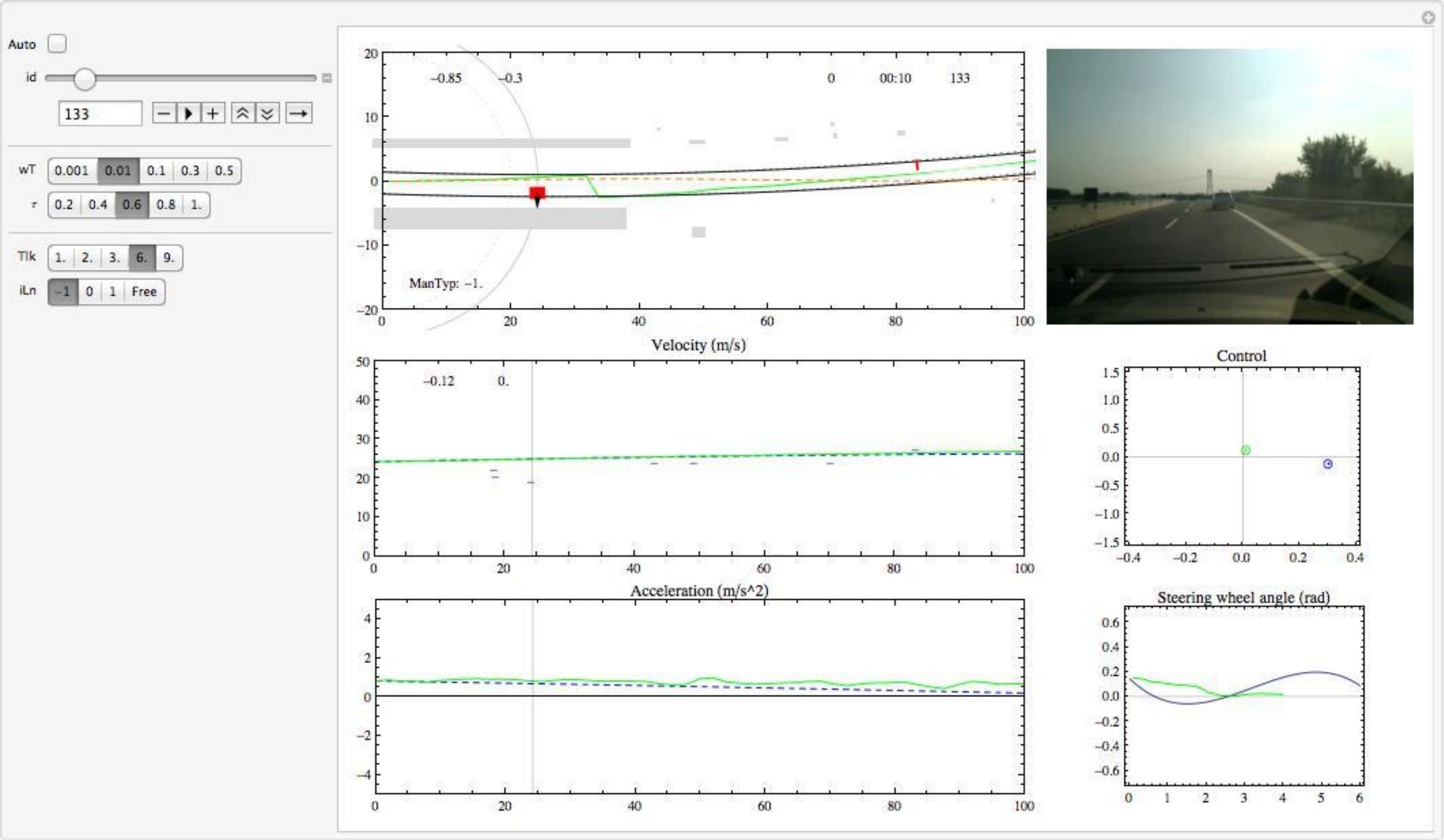
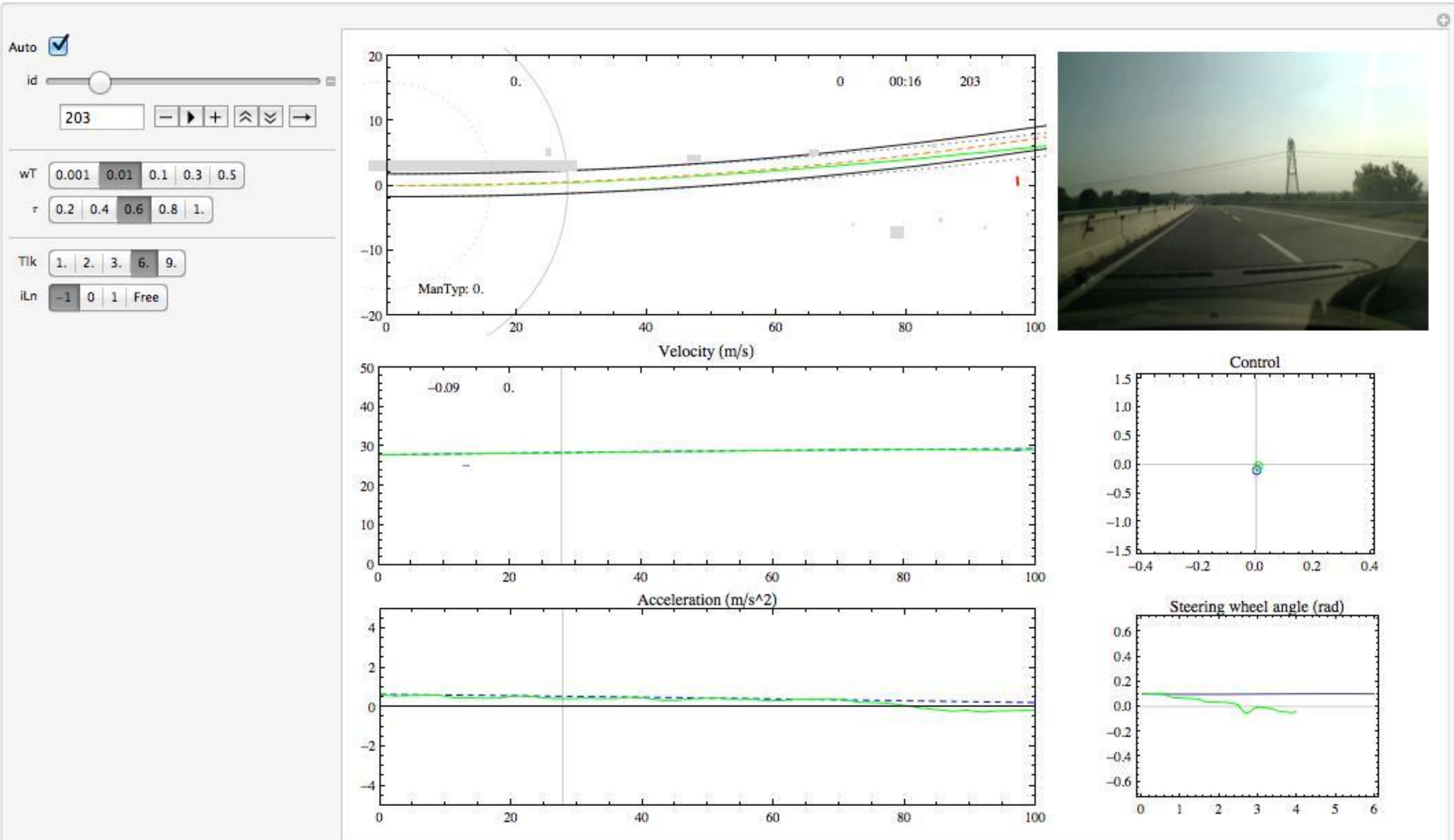
Frame 133

- What if passing on the right? Needs 9 s @ 0.3 rad/s but 0.85 to clear.



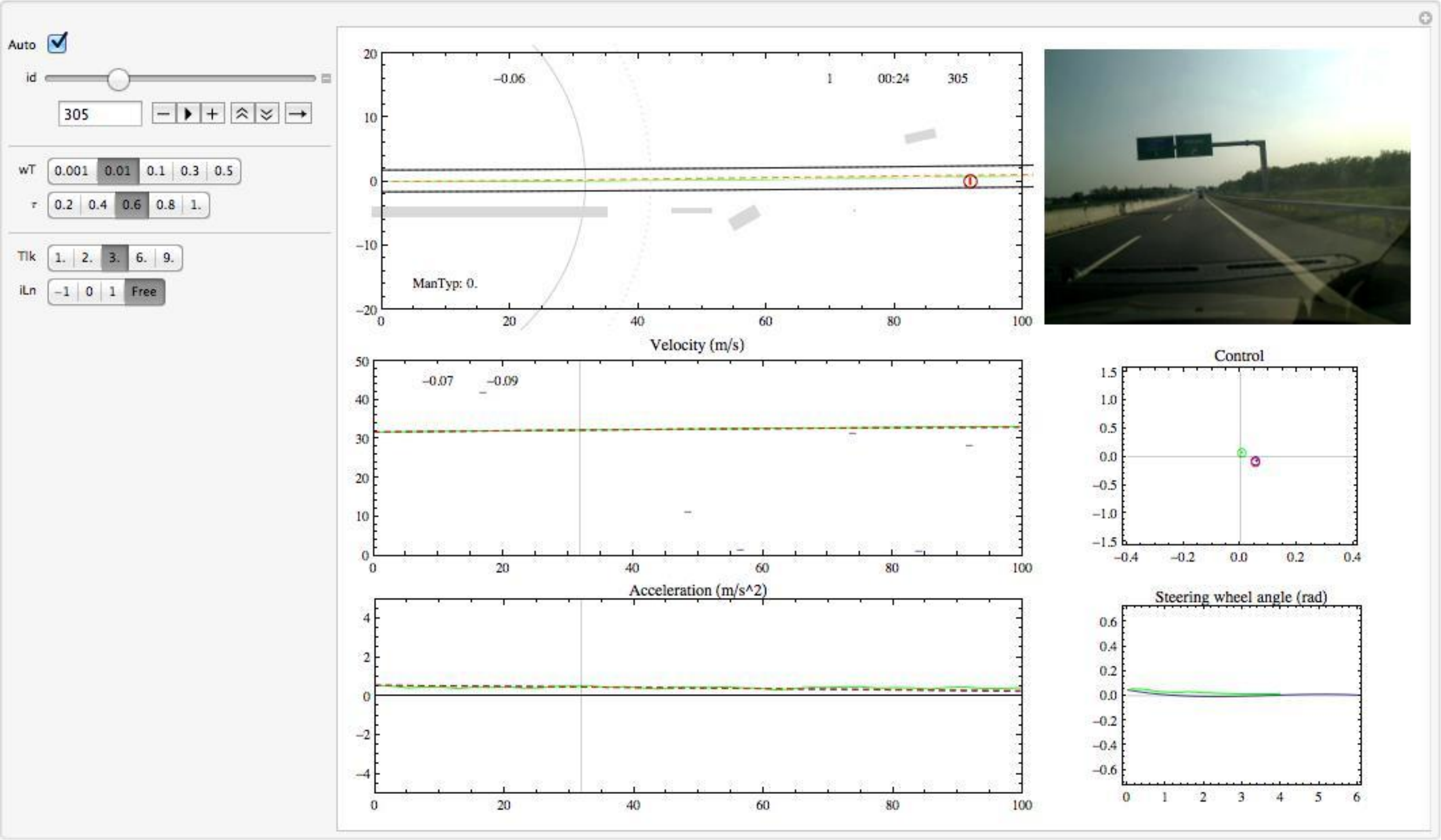
Frame 203

- Limitation due to short detection range of the camera.



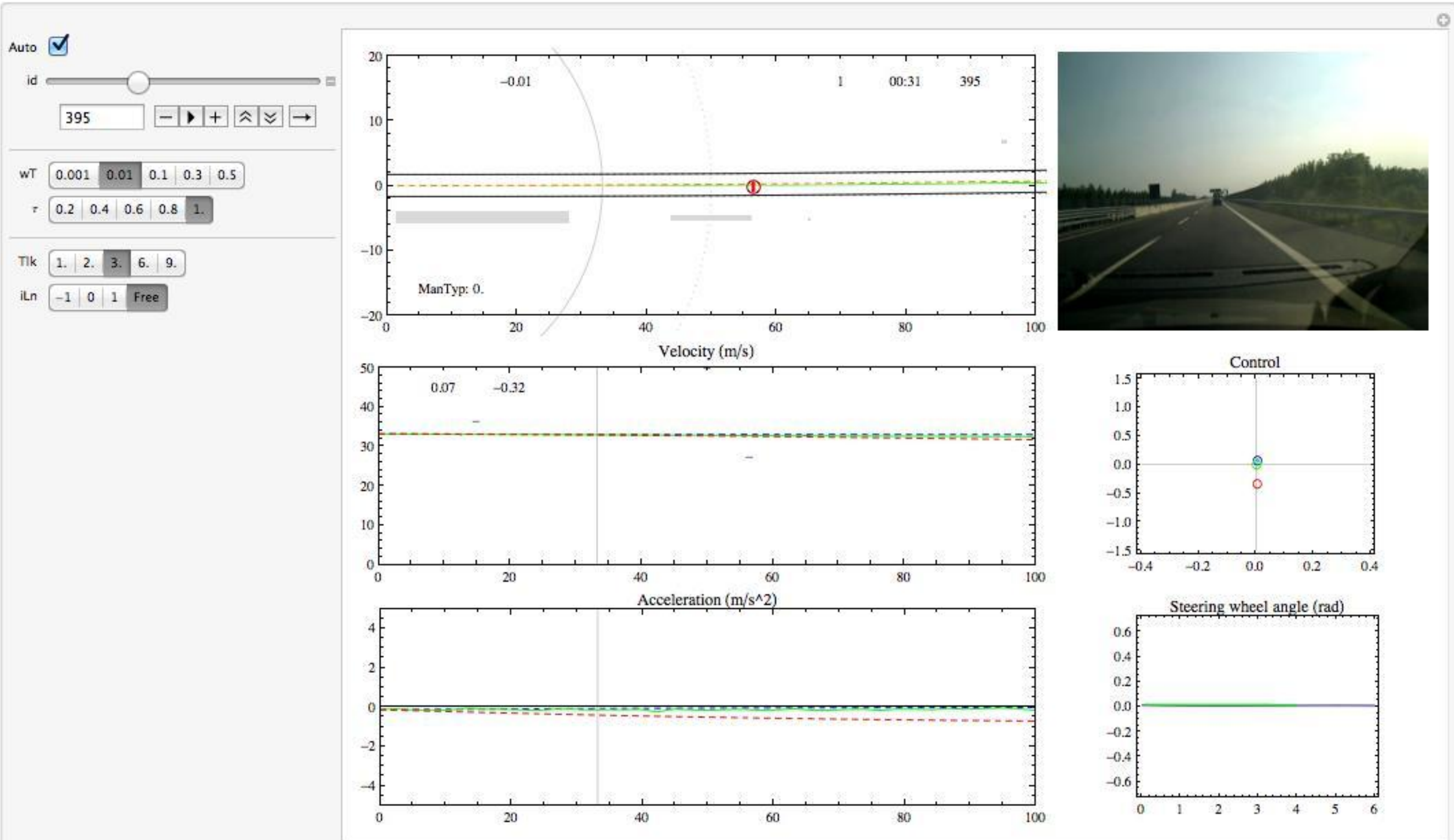
Frame 305

- Early danger detection.



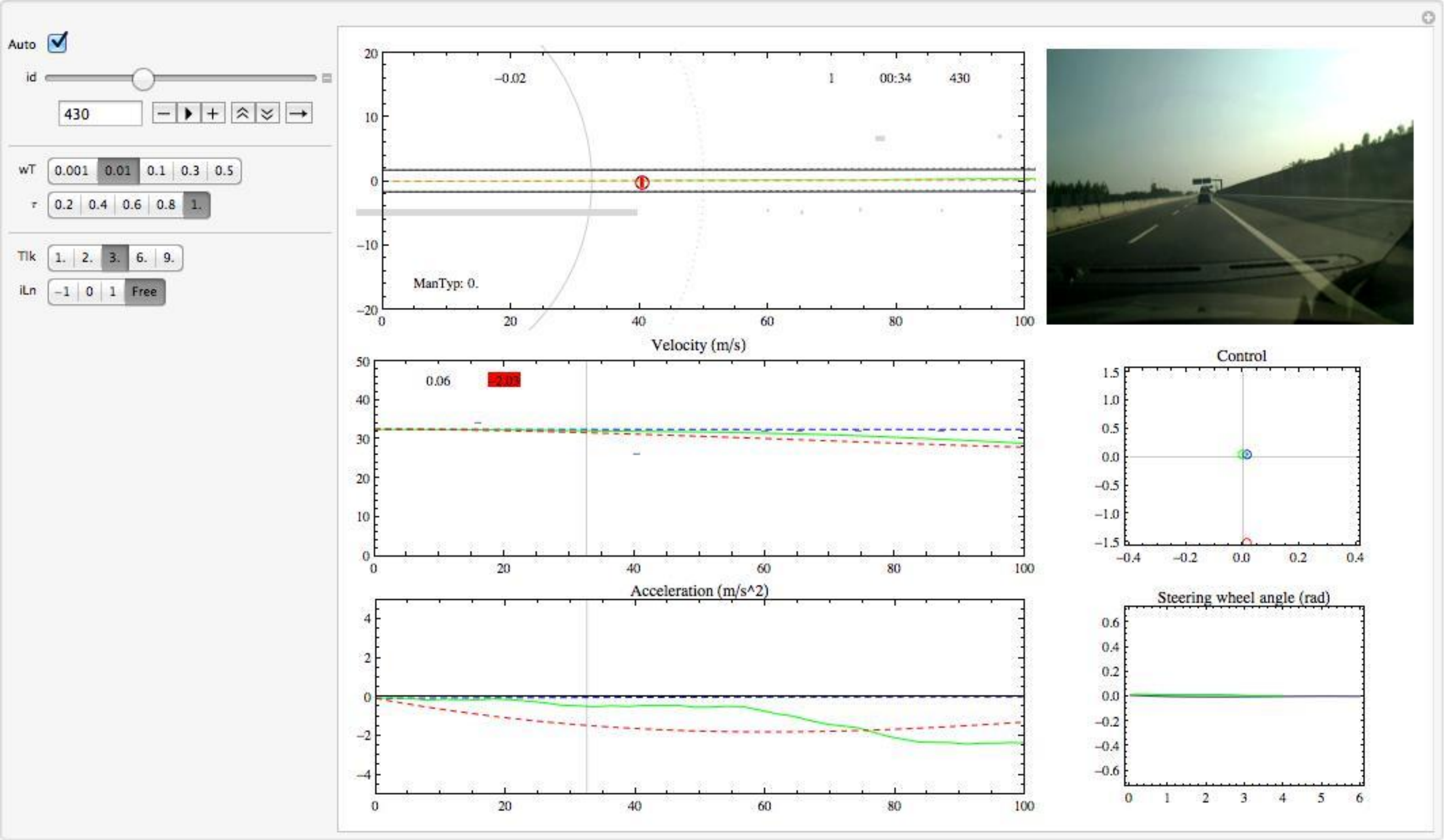
Frame 395

- Keeping 1s time headway is no difficult.



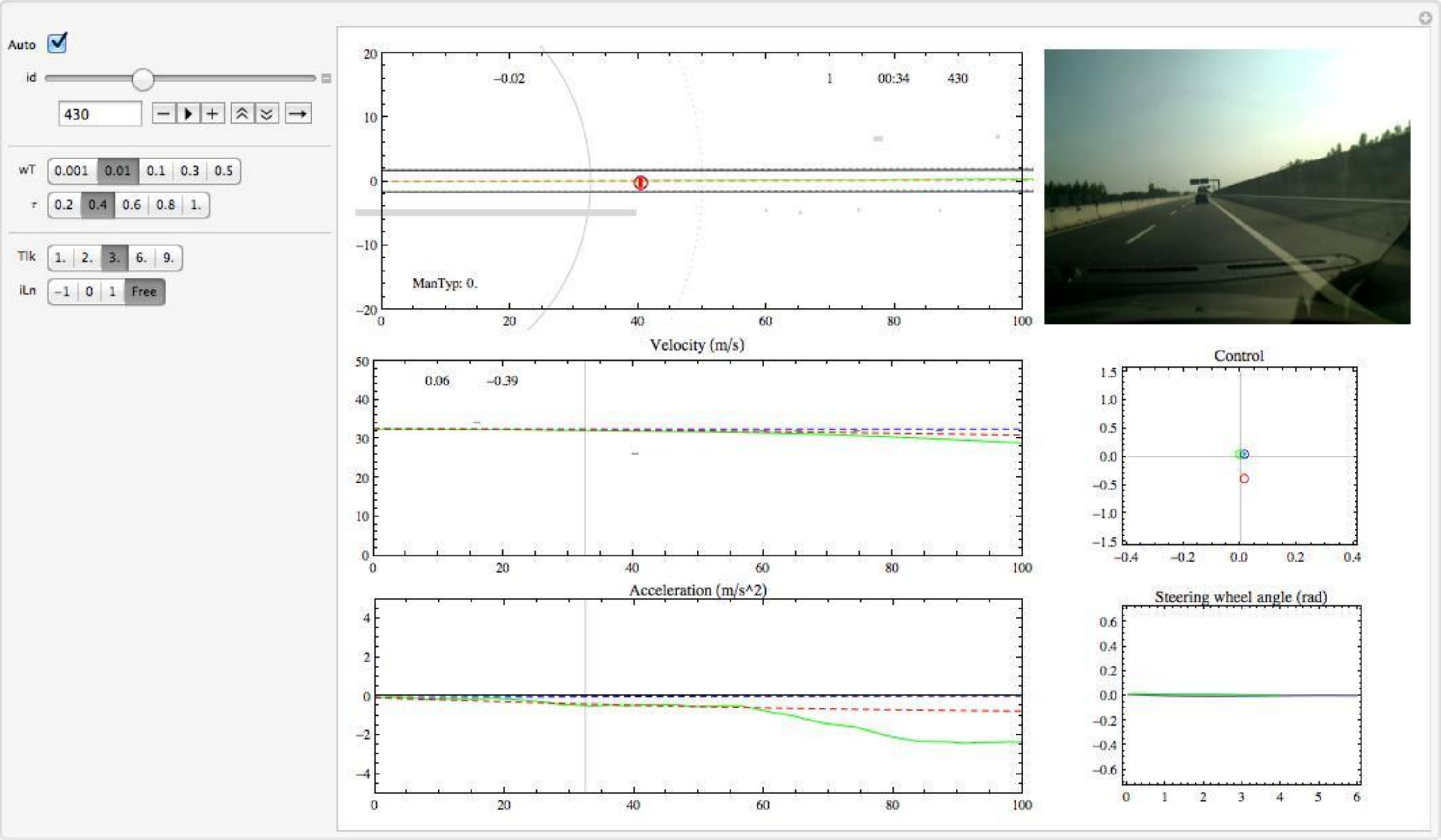
Frame 430

- Keeping 1s time headway is no longer within human capabilities.



Frame 430

- Indeed the driver goal is time headway ~ 0.4 s!



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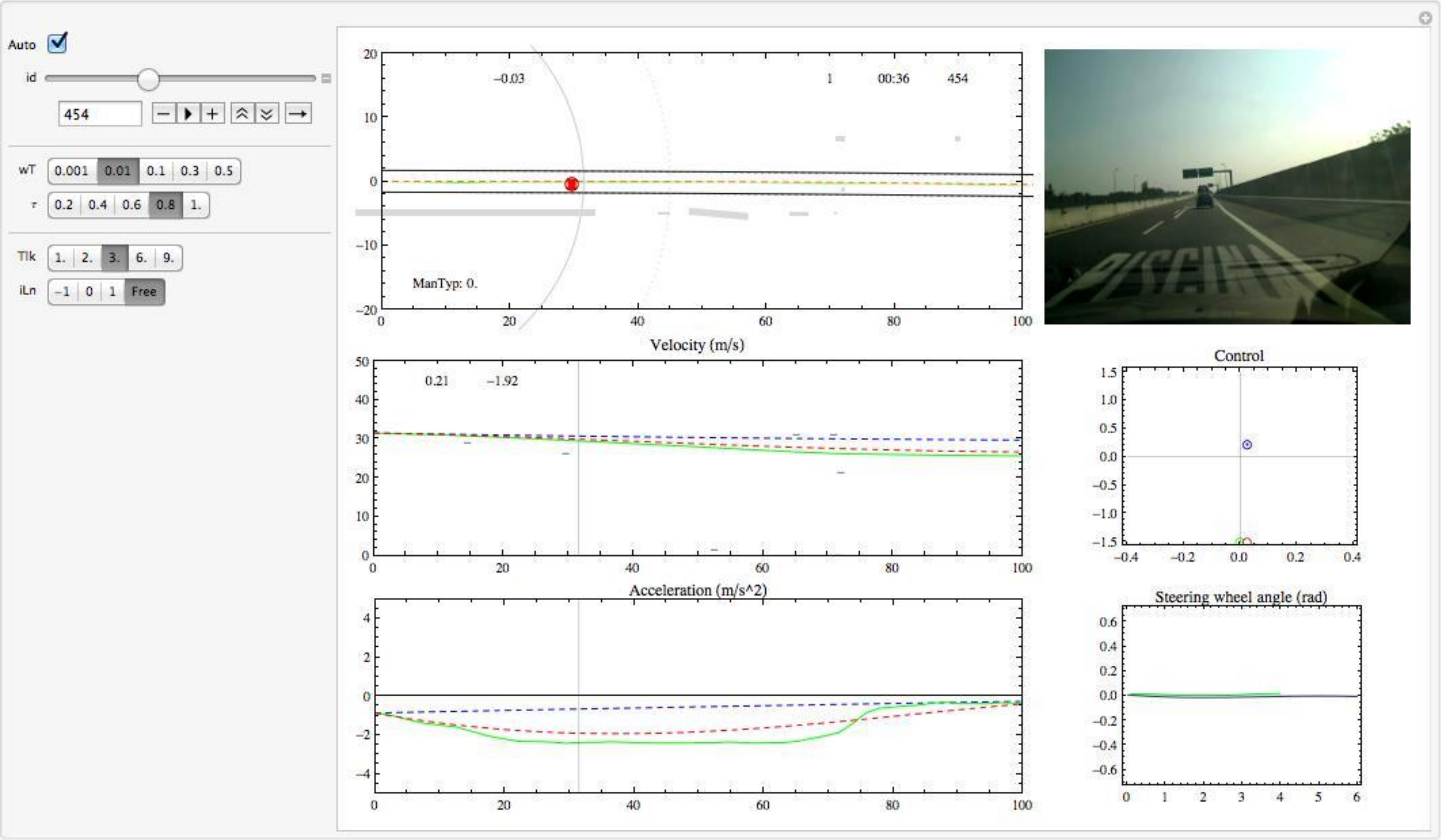
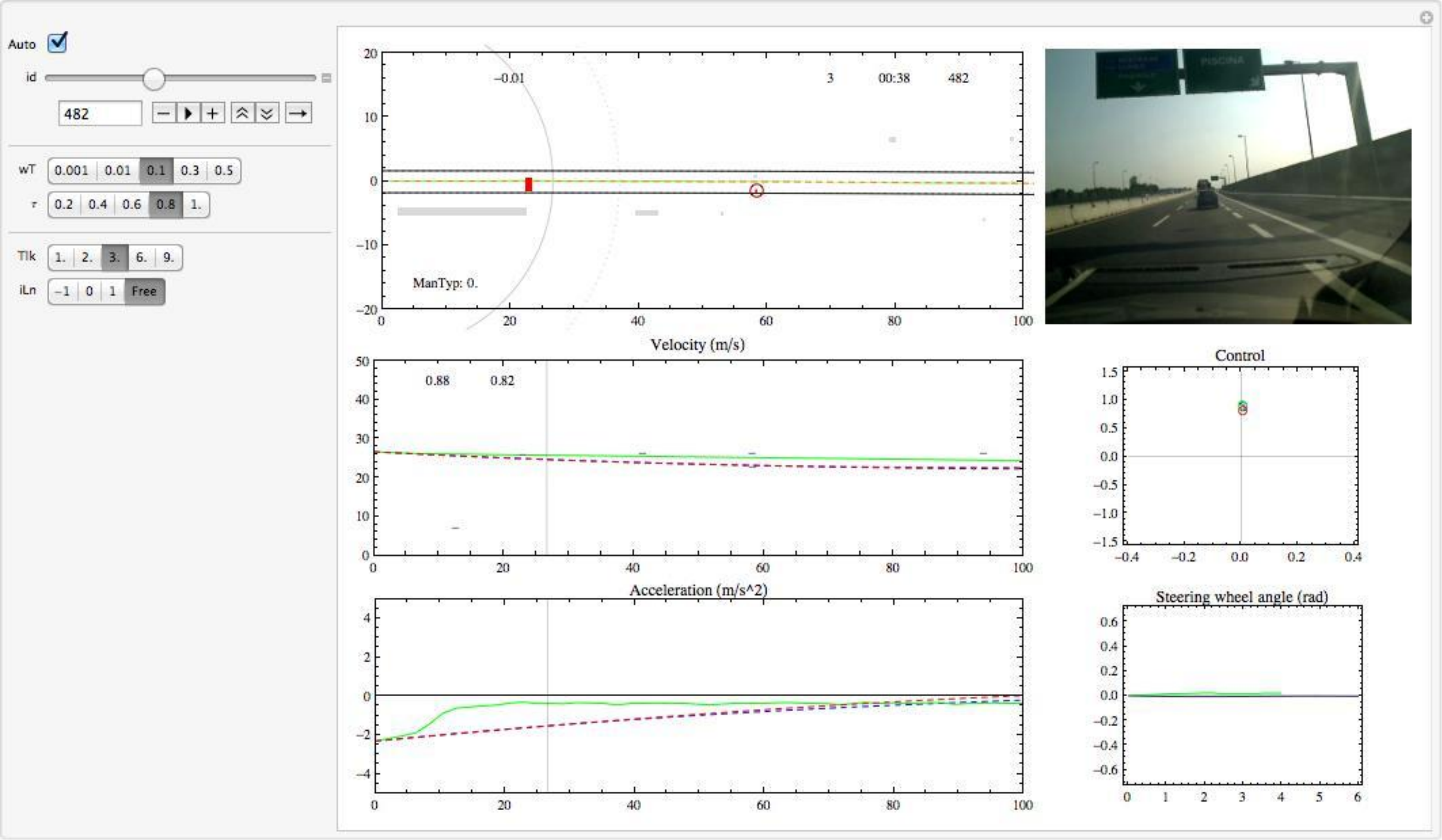
Frame 454

- Now the driver resets his goal to time headway ~ 0.8 s.



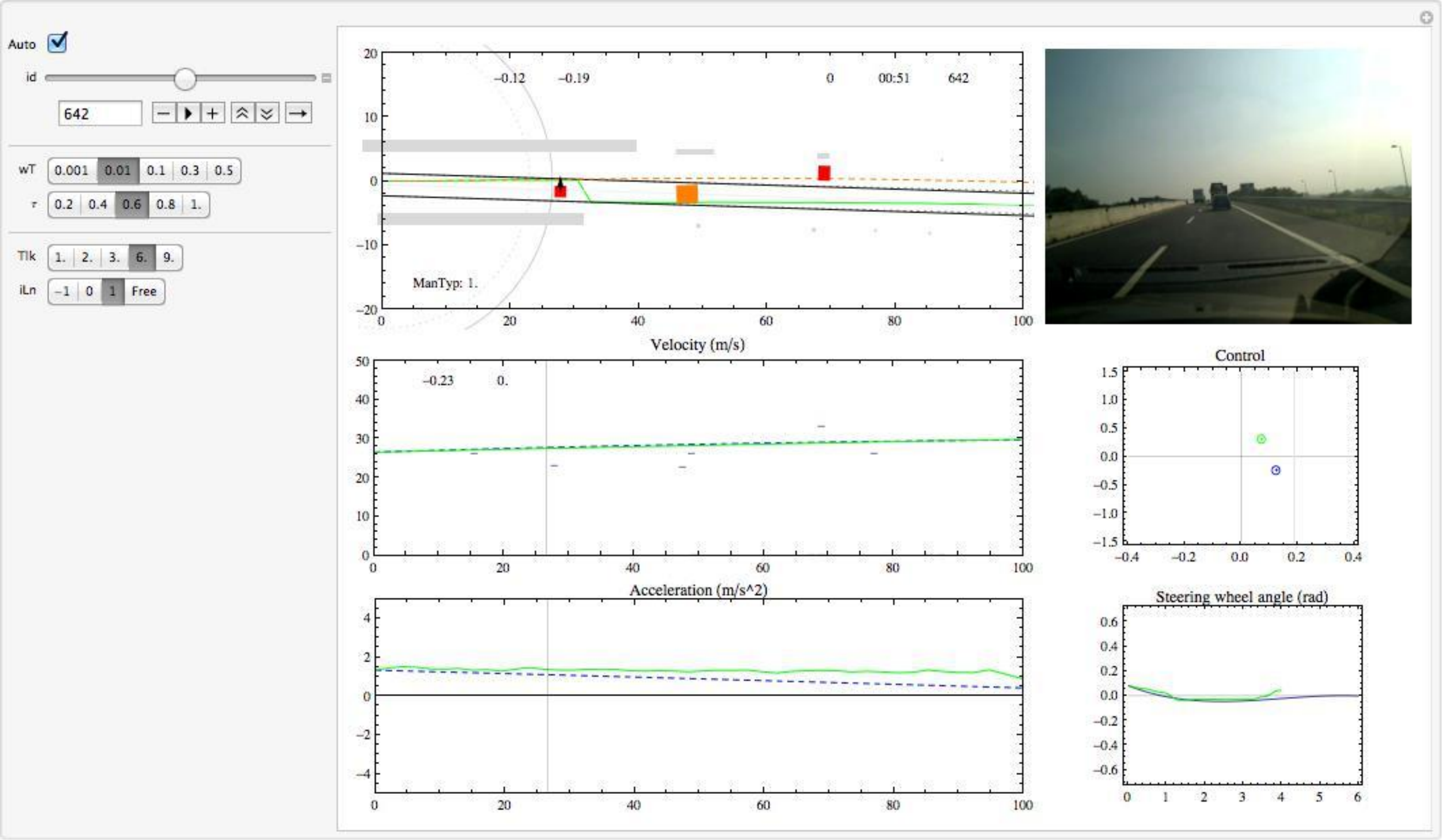
Frame 482

- Now the driver resumes a “faster” (wT=0.1) criterion.



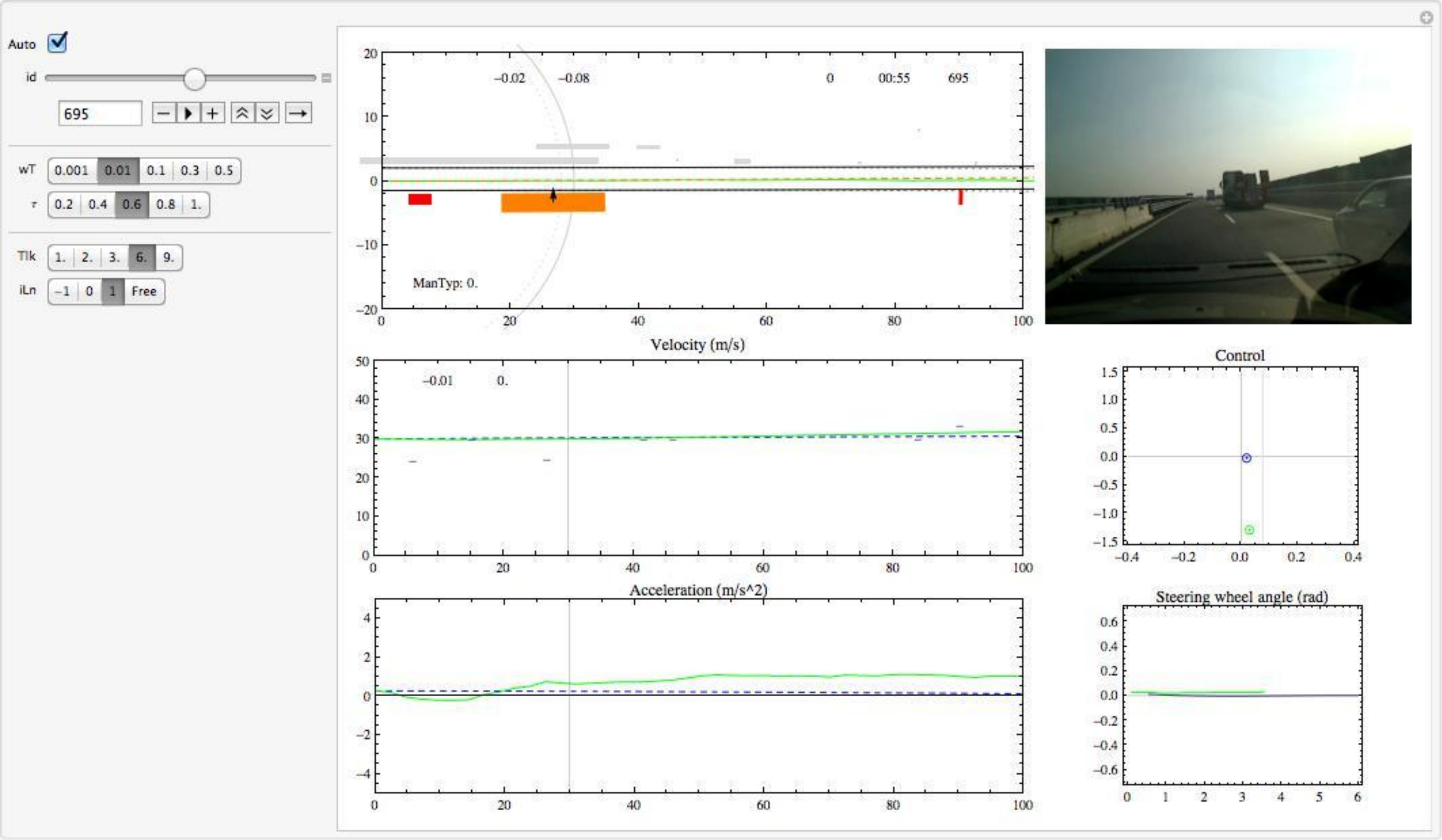
Frame 642

- Another lane change with obstacle to be cleared.



Frame 695

- Another obstacle to be cleared.



Conclusions

- Implementation of a co-driver using the following ideas:
  - Theory of cognition by emulation.
  - Subsumptive architecture (per competence levels).
  - Humanlike motor primitives based on optimal control.
- Inference of driver goals.
- Scalable, robust and extendable system.
- Works with reduced set of sensors.

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Accident avoidance by active intervention for Intelligent Vehicles

Thank you.

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by the European Commission

SEVENTH FRAMEWORK
PROGRAMME

Mauro Da Lio (Full Professor)
Università degli Studi di Trento
Via Mesiano 77, 38100 Trento (Italy)
mauro.dalio@ing.unitn.it

UNIVERSITÀ DEGLI STUDI
DI TRENTO