CommonRoad: Composable Benchmarks for Motion Planning on Roads

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June 13, 2017
Examples of IV’16 Papers on Motion Planning

Chen et al.: Combining Task and Motion [...]

Guo et al.: Adaptive Vehicle Longitudinal [...] Guo et al.: Learning-based Trajectory [...]

Reproducible? Comparable?

Gu et al.: Runtime-Bounded Tunable Motion Planning for Autonomous Driving

Klingelschmitt et al.: Probabilistic Situation [...]

Schmied et al.: Scenario Model Predictive [...]
Required Ingredients for Motion Planning Problems

Scenario

Road network
Required Ingredients for Motion Planning Problems

Scenario

Road network, initial state $x_0$
Required Ingredients for Motion Planning Problems

Scenario

Road network, initial state $x_0$, goal region $\mathcal{G}$
Required Ingredients for Motion Planning Problems

Scenario

Road network, initial state $x_0$, goal region $G$, static obstacles
Required Ingredients for Motion Planning Problems

Scenario

Road network, initial state $x_0$, goal region $G$, static obstacles, dynamic obstacles (including movement over time)
Required Ingredients for Motion Planning Problems

**Vehicle model**

\[ \dot{x}(t) = f(x(t), u(t)) \]

\( x \): state, \( u \): input

**Scenario**

Road network, initial state \( x_0 \), goal region \( G \), static obstacles, dynamic obstacles (including movement over time)
Required Ingredients for Motion Planning Problems

**Vehicle model**

\[ \dot{x}(t) = f(x(t), u(t)) \]

- \( x \): state, \( u \): input

**Cost function**

\[ J_C = \Phi_C(x(t_0), t_0, x(t_f), t_f) + \int_{t_0}^{t_f} L_C(x(t), u(t), t) \, dt \]

- \( \Phi_C \): terminal costs,
- \( L_C \): running costs

**Scenario**

Road network, initial state \( x_0 \), goal region \( G \), static obstacles, dynamic obstacles (including movement over time)
Examples of Benchmarks in Related Areas

**Robotic grasping**
OpenGrasp

**Simultaneous localization and mapping (SLAM)**
OpenSLAM

**Computer vision**
KITTI Vision Benchmark Suite
### Composable Benchmarks with a Unique ID

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Collaboration (C-): [PM1,PM2]:[M-JB1,SA1]:C-NGSIM_(...)
Models

Point-mass model (PM)
- Holonomic system
- $\ddot{x} = a_x$, $\ddot{y} = a_y$

Kinematic single-track model (KS)
- Nonholonomic system
- Considers minimum turning radius
- No tire slip

Single-track model (ST)
- Considers tire slip
- Can explain understeer and oversteer
- No individual tire loads

Multi-body model (MB)
- Individual tire loads
- Effects from yaw, pitch, and roll
- Detailed suspension model
Cost Functions

Like the benchmarks, the cost functions are composable:

$$J_C(x(t), u(t), t_0, t_f) = \sum_{i \in I} w_i J_i(x(t), u(t), t_0, t_f),$$

where $I$ contains the IDs of partial cost functions and $w_i \in \mathbb{R}^+$ are weights. Examples:

- **Time:** $J_T = t_f$ (see Bobrow et al., 1988).
- **Acceleration:** $J_A = \int_{t_0}^{t_f} a(t)^2 \, dt$ (see Ziegler et al., 2014b).
- **Jerk:** $J_J = \int_{t_0}^{t_f} \dot{a}(t)^2 \, dt$ (see Werling et al., 2010).
- **Steering angle:** $J_{SA} = \int_{t_0}^{t_f} \delta(t)^2 \, dt$ (see Magdici et al., 2016).
- etc.

A set of useful weights is provided by cost-function IDs (e.g. $JB1$, $SA1$, and $WX1$).
Scenarios: Road Network

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Example of a complicated crossing in Munich:
Scenarios: Obstacles

- Known behavior
- Unknown behavior
- Stochastic behavior

Occupancy at final time of prediction horizon

Trajectory
Source for Known Behavior: Recorded Data

Camera facing US Interstate 80.

Coverage of individual cameras.

Next Generation Simulation (NGSIM) dataset:

1. Lankershim Boulevard
2. US Highway 101
Source for Unknown Behavior: SPOT

A Tool for Set-based Prediction of Traffic Participants (SPOT). Tool presented

Example:

(a) $t \in [1.5 \text{ s}, 2.0 \text{ s}]$.

(b) $t \in [0 \text{ s}, 3.0 \text{ s}]$.

**Computation time:** $\approx 100$ times faster than maneuver time (MATLAB, Intel i7, 2.6GHz); total time: 25 ms (3 parallel processes).
Example

- **Vehicle model:** M-KS1 (modification: $v_S$ is changed to $v_S \to \infty$).
- **Cost function:** SM1.
- **Scenario:** NGSIM_US101_0.

Thus, the unique ID of this example is **M-KS1:SM1:NGSIM_US101_0**.

**Possible solution:**

$t = 0.0$ s

$t = 2.5$ s

$t = 5.5$ s

- **ego vehicle**
- **obstacle A**
- **obstacle B**
Key Features

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- **Independence:** Our benchmarks are independent from planning libraries.
INTRODUCTION TO COMMONROAD

Numerical experiments for motion planning of road vehicles require numerous ingredients: vehicle dynamics, a road network, static obstacles, dynamic obstacles and their movement over time, goal regions, a cost function, etc. Providing a description of the numerical experiment precise enough to reproduce it might require several pages of information. Thus, only key aspects are typically described in scientific publications, making it impossible to reproduce results - yet, reproducibility is an important asset of good science.

Composable benchmarks for motion planning on roads (CommonRoad) are proposed so that numerical experiments are fully defined by a unique ID; all required information to reconstruct the experiment can be found on the CommonRoad website. Each benchmark is composed by a vehicle model, a cost function, and a scenario (including goals and constraints). The scenarios are partly recorded from real traffic and partly hand-crafted to create dangerous situations.

We hope that CommonRoad saves researchers time since one does not have to search for realistic parameters of vehicle dynamics or realistic traffic situations, yet having the freedom to compose a benchmark that fits one's needs.

REFERENCES

CommonRoad is introduced in our paper M. Althoff, M. Koschi, and S. Manzinger, "CommonRoad: Composable Benchmarks for Motion Planning on Roads," in Proc. of the IEEE Intelligent Vehicles Symposium, 2017. [to appear]

SUGGEST NEW BENCHMARKS

We offer you the possibility to suggest new benchmarks. If you want to contribute a new component, e.g. a scenario, please contact us.
Conclusions

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- Mix of recorded and constructed scenarios as well as scenarios on highways, on rural roads, and in urban settings.
- Our platform-independent repository can be extended by other researchers and will also be extended by ourselves.