

MAD76 Academy: H. MATLAB/Simulink

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1 Agenda

- MATLAB/Simulink must have been installed and configured on your Linux PC (see Installation Guide)
- Model-in-the-Loop Simulation for Controller Design (see Section 1.1)
- Interfaces of vehicle dynamics and motion control (see Section 1.2)
- Software-in-the-Loop Simulation for Controller Design (see Section 1.3)
- Real MAD76 Control (see Section 1.4)

Teaching Objectives

- Understand the operation and the interfaces of the Simulink models
- Learn how to control MAD76 with Simulink
- Learn how to use Simulink for adjusting the RC controls of MAD76 (see B. Adjust MAD76)

1.1 Model-in-the-Loop Simulation

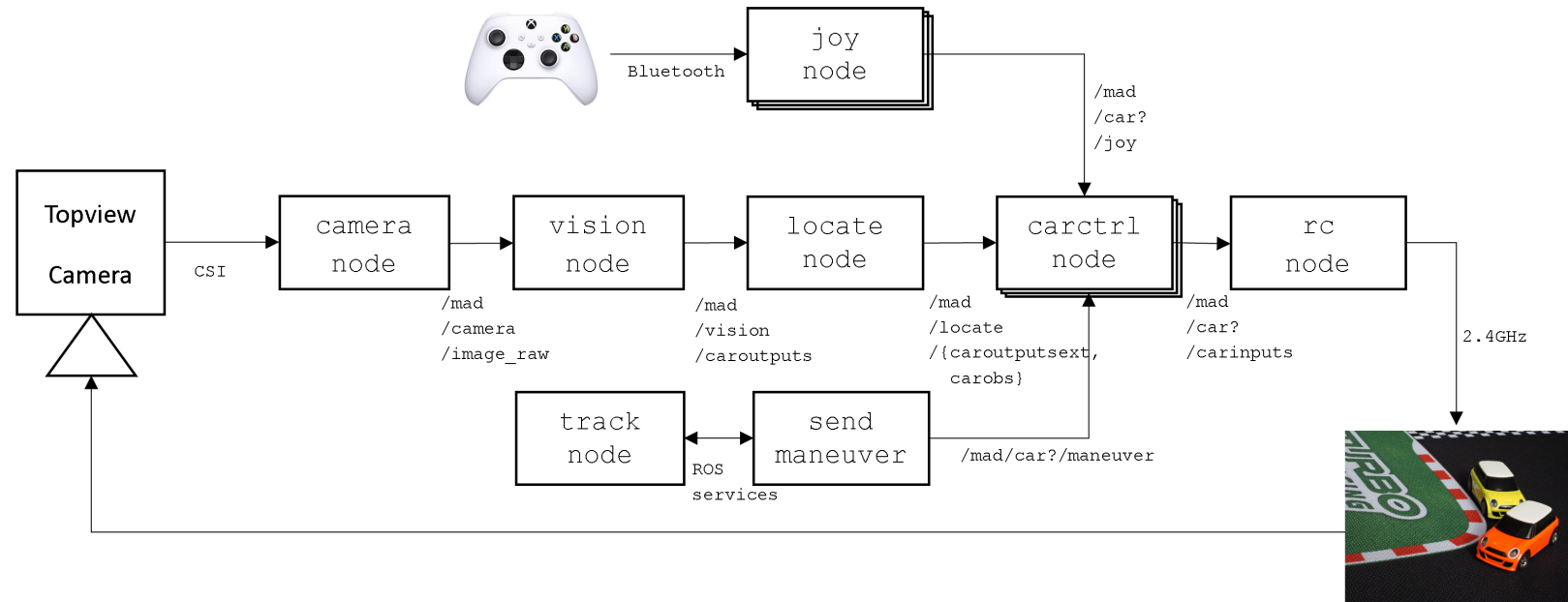


Figure 1: ROS2 nodes of MAD76 Driving Stack

- The Simulink model `s06_sig_template.slx` is the template model for vehicle dynamics modeling and controller design.

- Its purpose is to simulate the complete MAD76 including cars, camera, and control functions (software of driving stack).
- It is a template model with empty subsystems for vehicle dynamics and motion control functions modeling.
- It contains the subsystems modeling and simulation the ROS2 nodes of MAD76 in Figure 1 plus the vehicle dynamics:

ROS2 Node	Description	Simulink-Subsystem
camera_node	Rasberry Pi camera driver	Vision
visionnode	computer vision	Vision
locatenode	multi-object tracking	Locate
carctrlnode	motion planning and control for each individual car	Car0/Motion Control
rcnode	remote control signals output to 2.4GHz channel via SPI	not modeled
tracknode	track map	s06_data.m, t71_mad76_small.m
joy_node	optional node for manual control via joystick	not modeled
send_maneuver	maneuver messages (reference signals) for motion control	Maneuver0
real car	vehicle dynamics	Car0/Vehicle Dynamics

- Above table is for car with id 0 (orange/red car).
- The subsystems of car id 0 may be duplicated to simulate multiple cars.
- The vehicle dynamics of car id 0 are modeled by the subsystem Car0/Vehicle Dynamics.
- The motion control functions (driving stack software) for car id 0 are modeled by the subsystem Car0/Motion Control.

- As soon as you have finished testing in model-in-the-loop (MiL), you can reuse Car0/Motion Control for software-in-the-loop (SiL) testing and real MAD76 control in Sections 1.3 and 1.4.
- rcnode for remote control is not modeled. The actuation Car0/Vehicle Dynamics by Car0/Motion Control is assumed to be ideal. Input delays will be modeled as part of textttCar0/Vehicle Dynamics.
- Test your MATLAB/Simulink installation by simulating this model.

1. MATLAB on the Linux PC can only be started in the terminal. Enter

```
cd ~/src/mad76/matlab/vertical  
matlab2025a
```

2. Enter on the MATLAB prompt:

```
s06_sig_template
```

3. The model should run without errors and display initial positions of the vehicles in the MATLAB figure. But the car in the MATLAB figure is not moving, yet, because subsystems Car0/Vehicle Dynamics and Car0/Motion Control are empty.

- Make sure that `/src/mad76/matlab/vertical` always is the current directory in MATLAB.

- Never add this directory to the MATLAB search path. Otherwise, MATLAB slows down and there will be conflicts in opening Simulink models and MATLAB scripts.

1.2 Interfaces

- ROS2 messages in Figure 1 are modeled as Simulink bus signals in `s06_sig_template.slx`
- The main ROS2 messages / bus signals for motion control and vehicle dynamics are:
 - `mbmadmsgs::msg::CarInputs` for control signals

ROS2 Topic	/mad/car?/carinputs
ROS2 Message Type	<code>mbmadmsgs::msg::CarInputs</code>
Simulink Bus Signal Type	CARINPUTS
Car0/Vehicle Dynamics	carinputs inport
Car0/Motion Control	carinputs outport

The main elements are:

Element	Symbol	Datatype	Unit	Description
pedals	u_n	single	$\in [-0.2, 0.2]$	motor signal for thrust and braking
steering	δ_n	single	$\in [-0.93, 0.93]$	steering signal

- `mbmadmsgs::msg::CarOutputs` for measurement signals

ROS2 Topic	/mad/locate/caroutputs
ROS2 Message Type	<code>mbmadmsgs::msg::CarOutputsList</code>
Simulink Bus Signal Type	CAROUTPUTS
Car0/Vehicle Dynamics	caroutputs outport
Car0/Motion Control	-

The main elements are:

Element	Symbol	Datatype	Unit	Description
s	$[s_1, s_2]^T$	single	m	rear axle center position in fixed frame
psi	ψ	single	rad	yaw angle

- `mbmadmsgs::msg::CarObsList` for car observations / process variables (position, speed, yaw angle, etc.)

ROS2 Topic	/mad/locate/carobs
ROS2 Message Type	<code>mbmadmsgs::msg::CarObsList</code>
Simulink Bus Signal Type	CAR_OBS array for list of all cars
Car0/Vehicle Dynamics	-
Car0/Motion Control	carobs inport

The main elements are:

Element	Symbol	Datatype	Unit	Description
<code>v</code>	$y = v$	single	m/s	rear axle center speed
<code>s</code>	$[s_1, s_2]^T$	single	m	rear axle center position in fixed frame
<code>psi</code>	ψ	single	rad	yaw angle

- `mbmadmsgs::msg::DriveManeuver` for maneuvers and reference signals

ROS2 Topic	/mad/car?/maneuver
ROS2 Message Type	<code>mbmadmsgs::msg::DriveManeuver</code>
Simulink Bus Signal Type	DRIVEMANEUVER
Car0/Vehicle Dynamics	-
Car0/Motion Control	maneuver inport

The main elements are:

Element	Symbol	Datatype	Unit	Description
<code>vmax</code>	$w = v^*$	single	m/s	setpoint (reference) for speed control

1.3 Software-in-the-Loop Simulation

- Simulink model `c71_car0_template.slx` is the template model for code generation
- Simulink simulates `c71_car0_template.slx` as a ROS2 node replacing the ROS2 node `carctrlnode` in Figure 2
- All other ROS2 nodes of Figure 2 run as usual
- Start this ROS2 environment in manual simulation mode (without MAD76 driving stack in `carctrlnode`)

```
ros2 launch mbmad madpisimman.launch
```

- Start the simulation of `c71_car0_template.slx`. Enter on the MATLAB prompt:

```
cd ~/src/mad76/matlab/vertical  
c71_car0_template
```

- Send a maneuver message to the Simulink model, so that the main subsystem is enabled

```
ros2 run mbmadcar send_maneuver.py 0 0.2 0.5
```

- You can now manually control the orange car with id 0 by manipulating the sliders in subsystem Motion Control and `carinputs msg/Motion Control/Sliders` or `Joystick/Sliders`

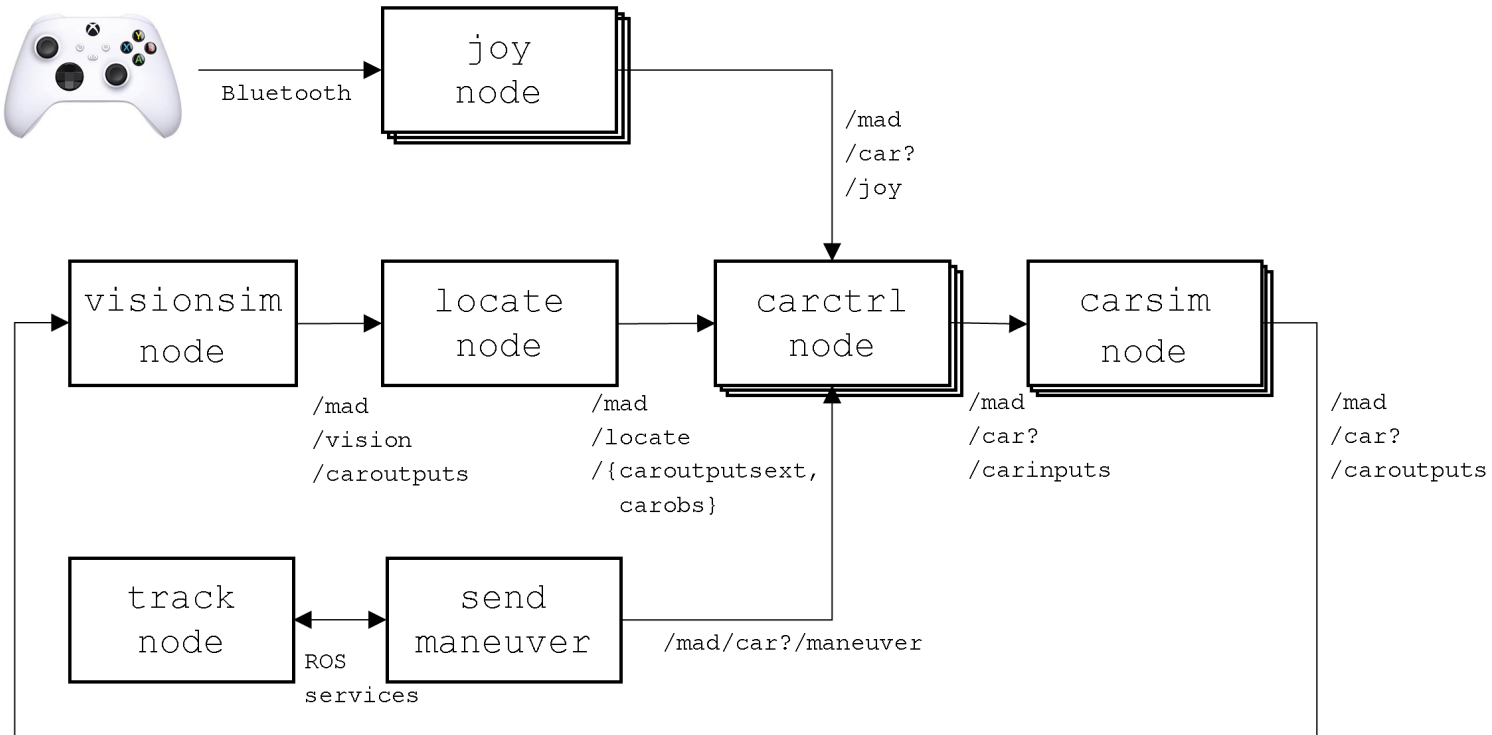


Figure 2: ROS2 nodes in SiL simulation mode

1.4 Real MAD76 Control

- The Simulink model `c71_car0_template.slx` is now simulated on the MAD76 Linux PC to control the real MAD76 cars
- All ROS2 nodes in Figure 1 run on the Raspberry Pi except for `carctrlnode`
- Simulink simulates `c71_car0_template.slx` as a ROS2 node replacing `carctrlnode` on the Linux PC
- ROS2 runs in a distributed environment consisting of Raspberry Pi and Linux PC
- ROS2 establishes network communication on Ethernet between Raspberry Pi and Linux PC
- Start the ROS2 environment on the Raspberry Pi without `carctrlnode`. Enter on the Raspberry Pi terminal:

```
ros2 launch mbmad madpiman.launch
```

- Start the simulation of `c71_car0_template.slx` on the MAD76 Linux PC. Enter on the MATLAB prompt:

```
cd ~/src/mad76/matlab/vertical  
c71_car0_template
```

and start the simulation by hitting the Run button in toolbar Simulation

- Send a maneuver message to the Simulink model, so that the main subsystem is enabled. Enter on the Raspberry Pi:

```
ros2 run mbmadcar send_maneuver.py 0 0.2 0.5
```

- First argument is the car identifier
 - 0 | orange/red car
 - 1 | yellow/white car
 - 2 | blue car
 - 3 | green car
- Second argument is the car reference speed $w = v^*$ in $\frac{\text{m}}{\text{s}}$

- Third argument is the lateral reference position

0	right curb
0.25	right lane
0.5	center line
0.75	left lane
1	left curb
-1	ideal line for low laptimes

- You can now manually control the orange/red car with id 0 by manipulating the sliders in subsystem Motion Control and carinputs msg/Motion Control/Sliders or Joystick/Sliders
- You can measure the vehicle states (elements of bussignal carobs/carobs(1)) including position, speed, and yaw angle in the Simulink Data Inspector
- Stopping the simulation triggers an emergency stop of the car
- You may now model control functions as part of subsystem Motion Control and carinputs msg/Motion Control/Sliders or Joystick/Sliders by replacing the sliders with your control algorithms
- You can use the sliders to adjust the RC controls according to B. Adjust MAD76
- Once finished with MiL testing, you can copy the motion control subsystem Car0/Motion Control from s06_sig_template.slx

to the subsystem Motion Control and carinputs msg/Motion Control in c71_car0_template.slx
for controlling the cars on the real MAD76 system