Moscow Automobile and Road Construction
State Technical University (MADI)

ENERGY EFFICIENCY OF AUTONOMOUS VEHICLES ON HILLY ROADS

Dr.Sc., Prof. Sergey Shadrin
MADI, “Cars” Chair

UK-Russia Workshop, 19-22 Nov. 2018

Agenda

1. Introduction:

- MADI Overview
- “Cars” Chair Research Activities

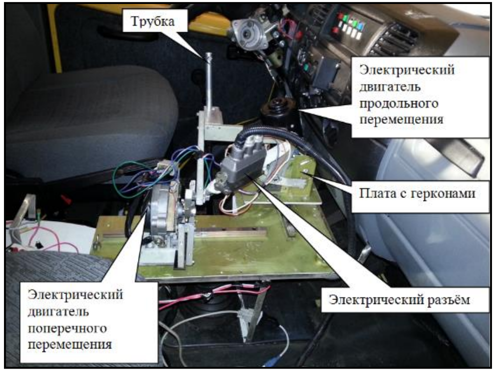
2. BaseTracK Project

3. Energy Consumption Efficiency on Hilly Roads

4. Results & Discussion

“Cars” Chair Research Activities – Autonomous Driving

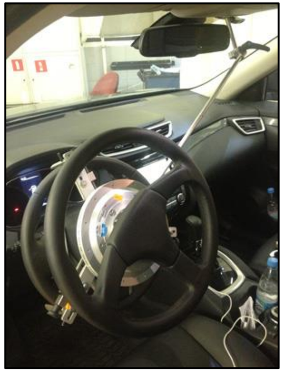
Automated GAZ-322132:



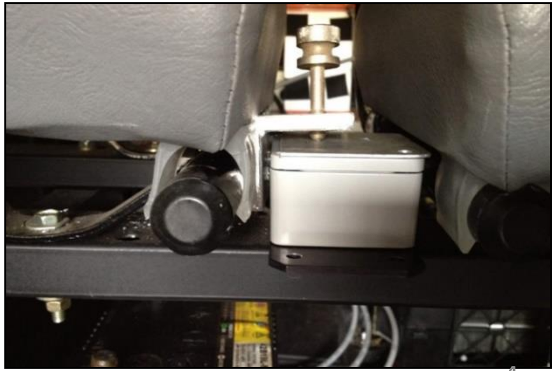
Autonomous Driving Technologies Testing Platform (Chevrolet Orlando):

“Cars” Chair Research Activities – Road Tests

Measuring equipment: Corrsys Datron, Kistler, IMC, Intrepid Control Systems, JAVAD navigation. Proving grounds: MADI, NAMI.



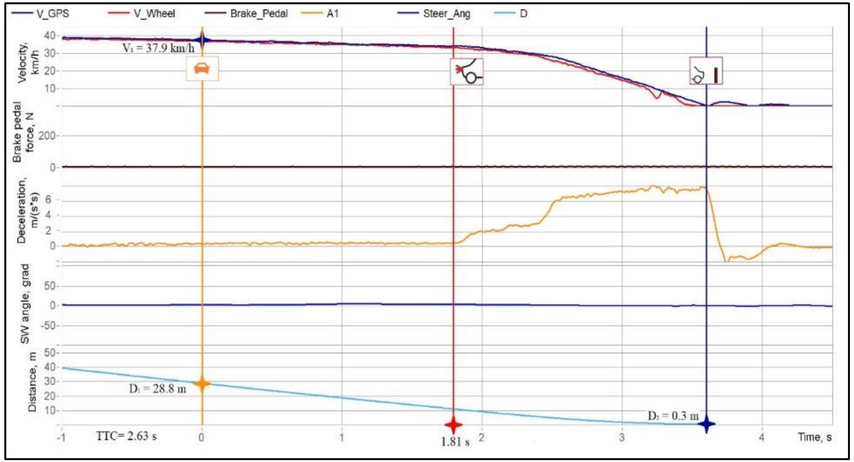
Time	Tx	Er	Description	ArbId/Header	Len	DataBytes	Network
19.993 ms			HS CAN $17B452B0	x17B452B0	7	02 EC 6C 6E 40 C0 C8	HS CAN
16.109 ms			HS CAN $12E9E6A0	x12E9E6A0	8	00 C9 00 C9 06 CB 00 C2	HS CAN
149.644 ms			HS CAN $17E80420	x17E80420	6	3F 00 1A 43 00 00	HS CAN
9.880 ms			HS CAN $1F1F0	x1F1F0	8	41 F4 28 00 BF FF 07 FF	HS CAN
19.376 ms			HS CAN $BD5FDF0	xBD5FDF0	7	00 00 70 14 00 00 FE	HS CAN
20.029 ms			HS CAN $17B80030	x17B80030	1	20	HS CAN
10.148 ms			HS CAN $4C1F6B0	x4C1F6B0	6	0F 26 07 05 06 FC	HS CAN
14.503 ms			HS CAN $E3052A0	xE3052A0	6	42 3C 1E 00 87 02	HS CAN
31.140 ms			HS CAN $17CCE6A0	x17CCE6A0	6	40 C8 1C 00 40 C8	HS CAN
10.078 ms			HS CAN $979BAB0	x979BAB0	8	88 80 00 C6 4C 77 FF 0C	HS CAN
20.055 ms			HS CAN $17B1FFF0	x17B1FFF0	8	00 00 01 1C B4 03 36 10	HS CAN
10.014 ms			HS CAN $71C0AA0	x71C0AA0	6	04 0C 04 0C 3C 0C	HS CAN
20.060 ms			MS CAN $4580BD0	x4580BD0	8	00 73 07 BC 80 00 FA 58	MS CAN
19.985 ms			HS CAN $17A9FFE0	x17A9FFE0	8	00 23 C5 00 F3 C5 FC 0F	HS CAN
39.972 ms			MS CAN $AD80BD0	xAD80BD0	8	03 8C 88 00 07 10 DC 27	MS CAN
20.005 ms			HS CAN $17ADBF70	x17ADBF70	8	00 30 00 5F FE 00 00 A6	HS CAN
29.882 ms			MS CAN $8AC0AB0	x8AC0AB0	7	00 08 03 00 01 02 00	MS CAN
19.378 ms			HS CAN $108CF1F0	x108CF1F0	8	0C C0 FF 04 6F C8 21 C8	HS CAN
19.378 ms			HS CAN $1544F9F0	x1544F9F0	8	80 00 80 00 80 00 80 00	HS CAN
19.694 ms			MS CAN $6840BE0	x6840BE0	8	00 3F 39 3C F4 01 27 38	MS CAN
25.251 ms			HS CAN $17BDFFE0	x17BDFFE0	5	40 20 22 F2 07	HS CAN

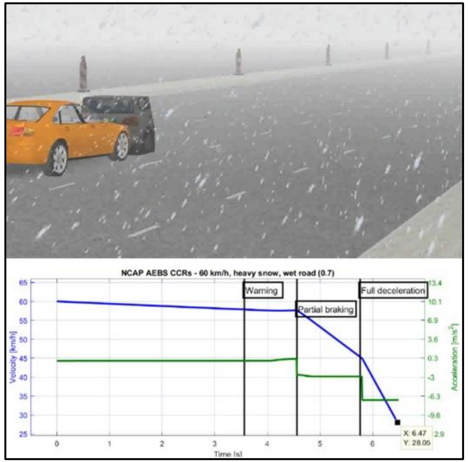


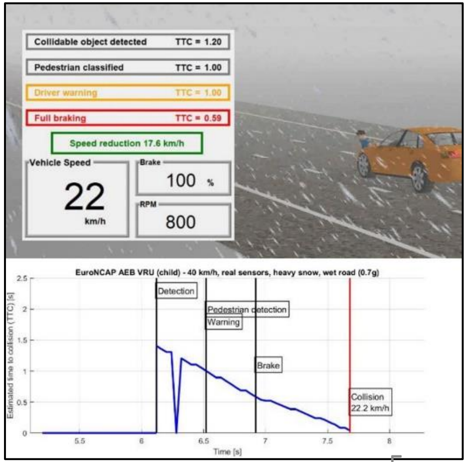
“Cars” Chair Research Activities – AV’s Testing System

ADAS virtual and road testing. Safety assessment of autonomous road vehicles with respect to the peculiarities of road and weather-climatic conditions in Russia.







BaseTracK Project – Autonomous Driving

BASETRACK

The overall act of driving can be divided into three levels[1] of driver effort:

1. Strategic
2. Tactical
3. Operational

Variability of maneuvers and driving modes

Challenges of object detection, classification, and road scene recognition

Decision-making problems

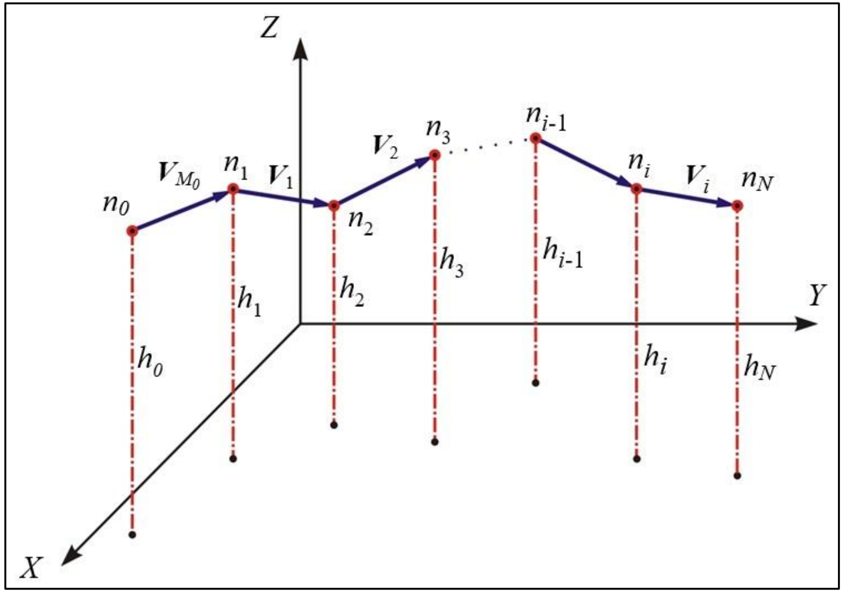
Invariable maneuvers
but variable driving modes

1) SAE J3016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, U.S.A.: SAE, 30 p., 2016.

Definition

BASETRACK

basetrack – an ideal track with a high-precision spatial driving route that contains additional blocks that provide optimal control of the vehicle based on the requested transport task and traffic conditions.

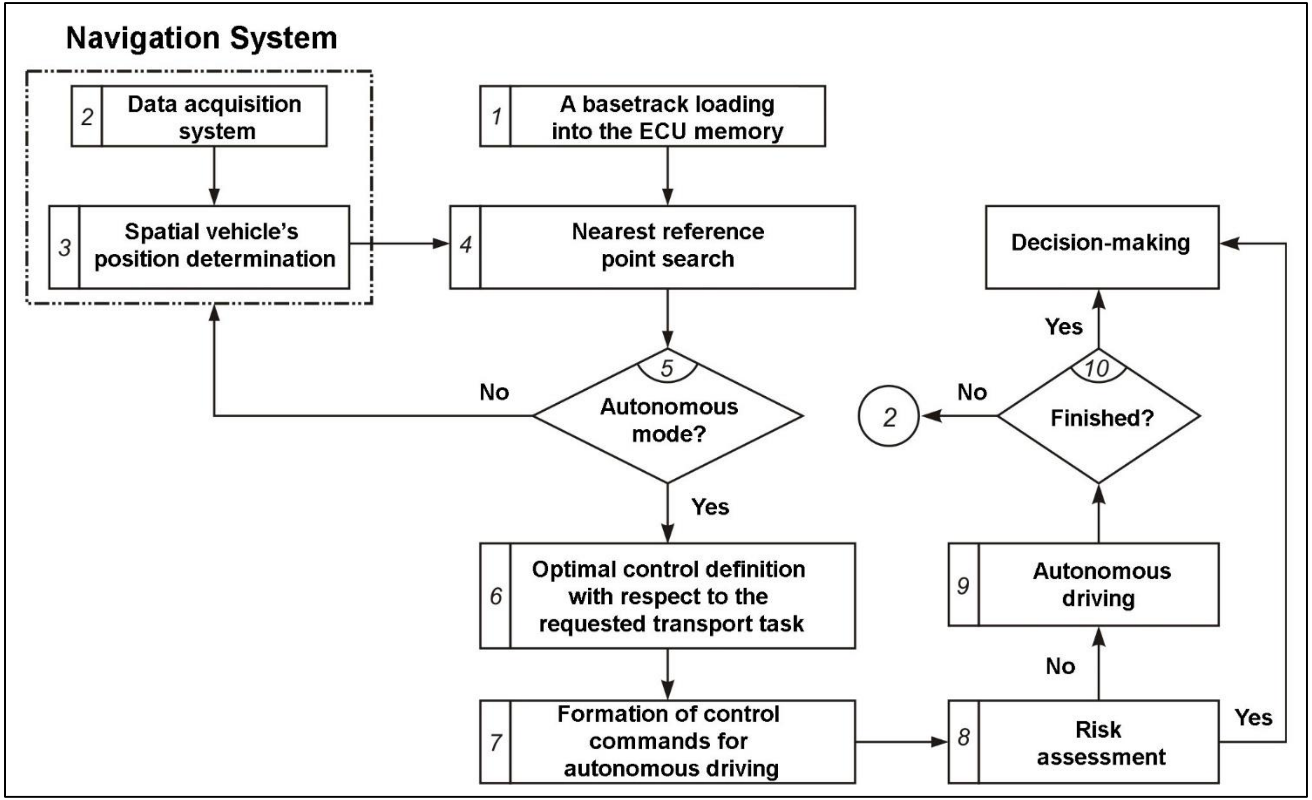


The basetrack structure includes:

- A dataset of the kinematic parameters of the vehicle’s motion;
- A navigation dataset;
- A dataset of referenced control actions;
- A dataset of road characteristics;
- A dataset of driving conditions with optimality criteria.

Scheme for Basetrack Driving in Autonomous Mode

BASETRACK



Example of Technology Implementation

BASETRACK

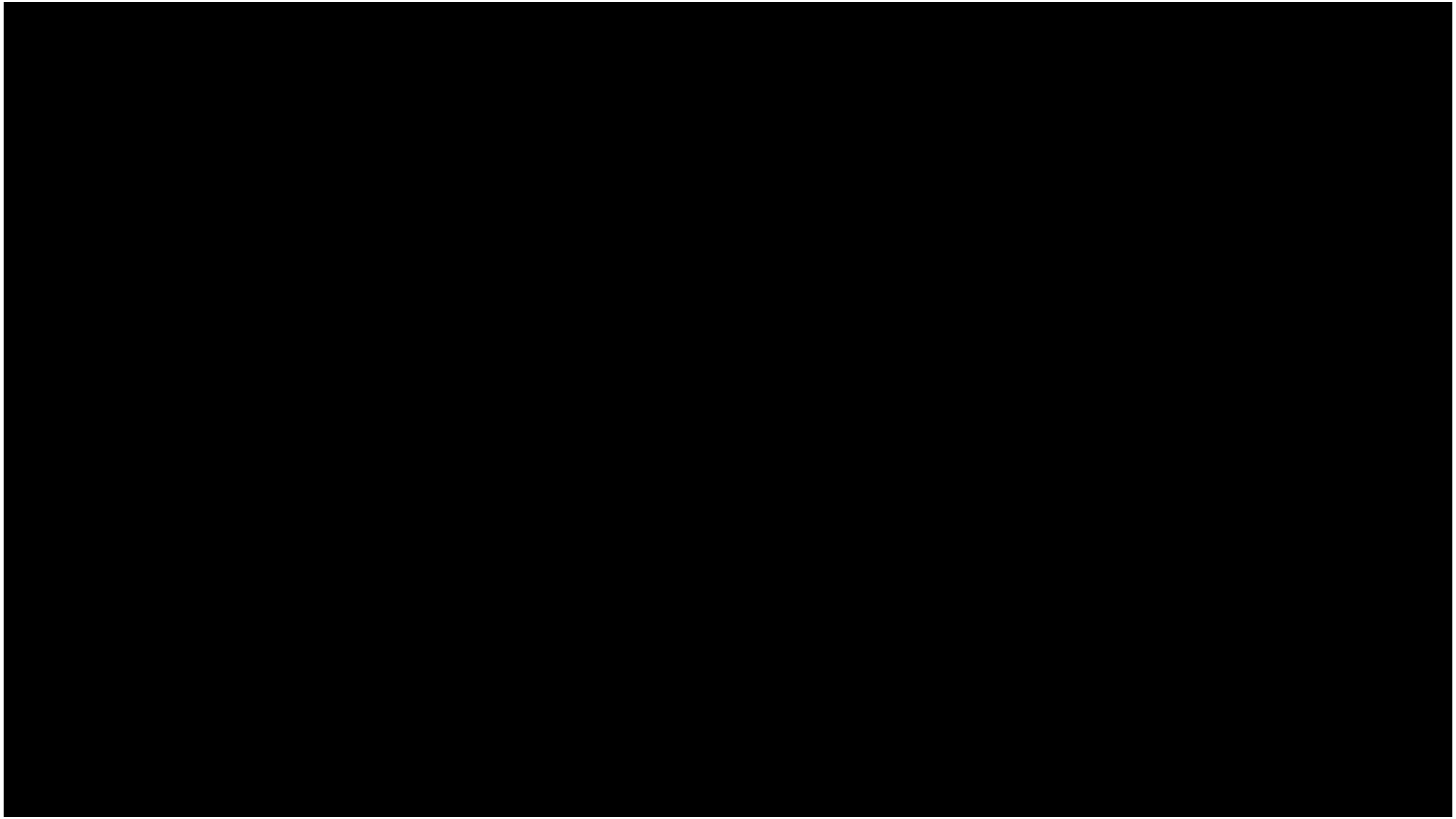
The experimental car was equipped with the following hardware:
- An electronic systems control module
- A brake pedal servo drive
- A hybrid navigation system (a satellite RTK DGPS
navigation system with inertial measurement unit and wheels-based navigation)
- An Ethernet network
- An autonomous driving module (an Android smartphone, with a Wi-Fi connection to the vehicle’s Ethernet network, with uploaded basetracks)

Basetrack cost:
database access
by subscription

Example of Technology Implementation

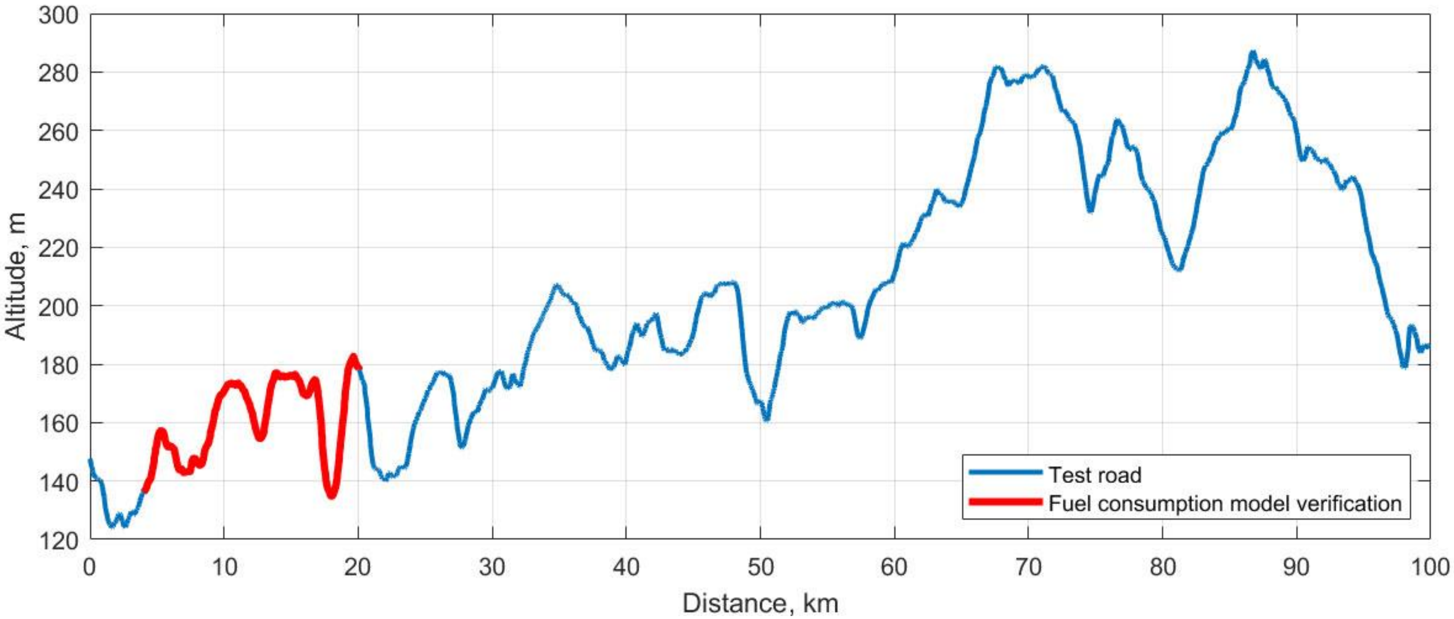
BaseTrack

Race on Ice Road



Energy Consumption Efficiency on Hilly Roads

BaseTrack



Federal highway altitudes (Moscow-Volokolamsk)

<u>Height accuracy:</u>
±10 cm

<u>Max difference of altitudes :</u>
163.3 m

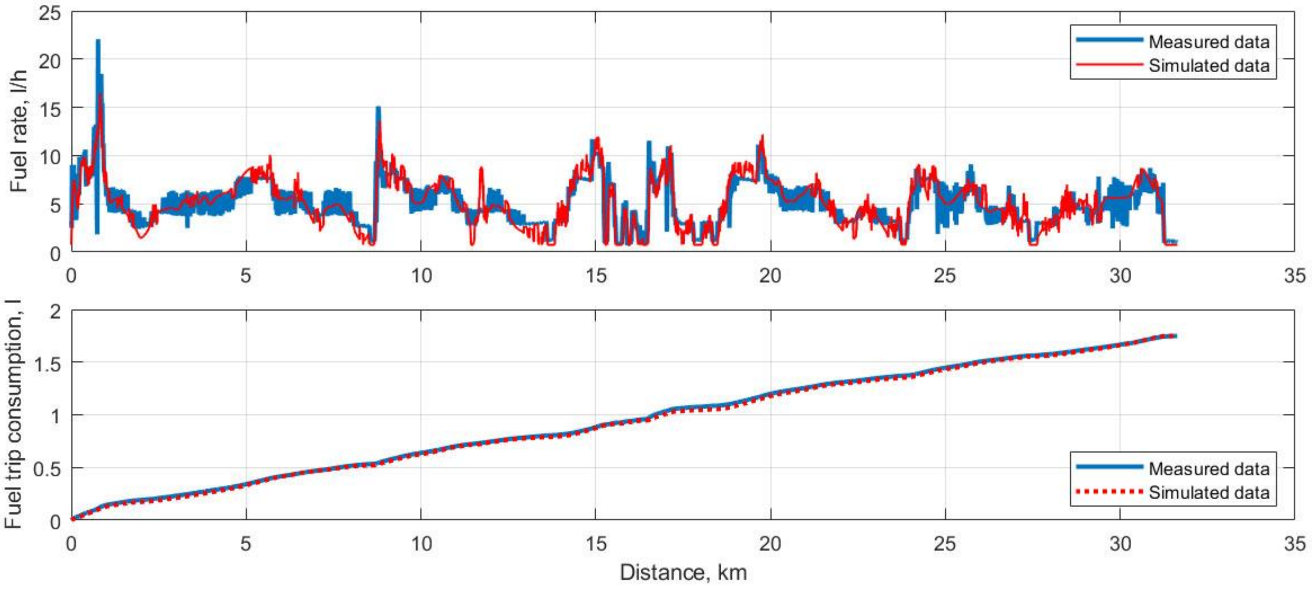
<u>Distance:</u>
99.8 km

Fuel Consumption Model Validation

BASETRACK

Fuel consumption per distance (IC):

$$B_{IC} = \frac{\int b_e \cdot \frac{1}{\eta} \cdot \left[\left(m \cdot f \cdot g \cdot \cos\alpha + \frac{\rho}{2} \cdot c_w \cdot A \cdot v^2\right) + m \cdot (a + g \cdot \sin\alpha) + B_r\right] \cdot v \cdot dt}{\int v \cdot dt}$$



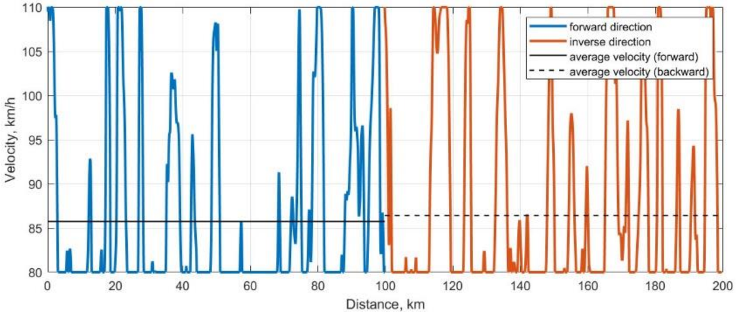
The adjusted parameters are as follows:

b_e=7.9292e-05 g/(W·s);
η=0.95;
m=1500 kg;
f=0.01;
g=9.81 m/s^2;
ρ=1.22625 kg/m^3;
c_w=0.3;
A=2.3768 m^2.

Simulation Results With and Without ISC {IC Engine}

BASETRACK

Intelligent Speed Control adjustment:



Veh. mass, kg	Forward direction (100 km)			Inverse direction (100 km)			Both ways (200 km)		
	Const.V km/h	80… 110 km/h	Econ., %	Const.V km/h	80… 110 km/h	Econ., %	Const.V km/h	80… 110 km/h	Econ., %
	Fuel cons., l	Fuel cons., l		Fuel cons., l	Fuel cons., l		Fuel cons., l	Fuel cons., l	
1400	4.61	4.51	-2.30	4.41	4.32	-2.02	9.02	8.82	-2.16
1500	4.76	4.63	-2.76	4.54	4.42	-2.58	9.30	9.05	-2.67
1600	4.91	4.75	-3.21	4.67	4.53	-3.13	9.58	9.27	-3.17
1700	5.05	4.87	-3.65	4.81	4.63	-3.64	9.86	9.50	-3.64
1800	5.20	4.99	-4.08	4.94	4.74	-4.12	10.14	9.73	**-4.10**

In both driving directions of the whole route, we compared two driving modes: 1) driving with intelligent speed control with speed regulation algorithm within 80…110 km/h, depending on whether the route has an upward or downward slope and 2) driving with a constant velocity as the average velocity of the first case (and therefore the same time).

Simulation Results With and Without ISC {Electric Vehicle}

BASETRACK

Energy consumption: $P_{total} = P_{bat_{out}} - P_{bat_{in}} = P_{bat_{tractive}} + P_{bat_{aux}} - P_{bat_{in}}$

$$B_{EV} = \frac{\int \frac{1}{(\eta_t \cdot \eta_m)} \cdot \left[\left(m \cdot f \cdot g \cdot \cos\alpha + \frac{\rho}{2} \cdot c_w \cdot A \cdot v^2 \right) + m \cdot (a + g \cdot \sin\alpha) + B_r \right] \cdot v \cdot dt}{\int v \cdot dt}$$

Veh. mass, kg	Forward direction (100 km)			Inverse direction (100 km)			Both ways (200 km)		
	Const.V km/h	80… 110 km/h	Econ., %	Const.V km/h	80… 110 km/h	Econ., %	Const.V km/h	80… 110 km/h	Econ., %
	Energy cons., kWH	Energy cons., kWH		Energy cons., kWH	Energy cons., kWH		Energy cons., kWH	Energy cons., kWH	
1400	13.28	13.13	-1.06	12.63	12.58	-0.37	25.91	25.72	-0.72
1500	13.68	13.48	-1.45	12.99	12.88	-0.84	26.68	26.37	-1.15
1600	14.09	13.84	-1.83	13.36	13.19	-1.30	27.45	27.02	-1.57
1700	14.51	14.19	-2.21	13.73	13.49	-1.77	28.24	27.68	-1.99
1800	14.93	14.54	-2.58	14.11	13.79	-2.23	29.03	28.33	**-2.41**

Results & Discussion

BASETRACK

1. Fuel consumption optimization for autonomous driving mode on a hilly test road over a distance of 200 km resulted in up to 4.1% savings for experimental vehicle and up to 2.4% for equivalent electric vehicle.

2. The economic and ecological advantages of the proposed basetrack concept are based on the correlation between the optimized control actions in autonomous driving mode and the requested transport task.

3. For the prototype of an autonomous road vehicle, a speed of 130 km/h was achieved for stable driving in the corridor of road lane without the use of road-marking recognition systems.

4. It is essential to solve the issues in optimal vehicle control for the autonomous driving mode in simulation with reference to a precise geoinformation environment.

THANK YOU FOR YOUR ATTENTION!

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