Smart and Green ACC

As Applied to a Through the Road Hybrid Electric Vehicle

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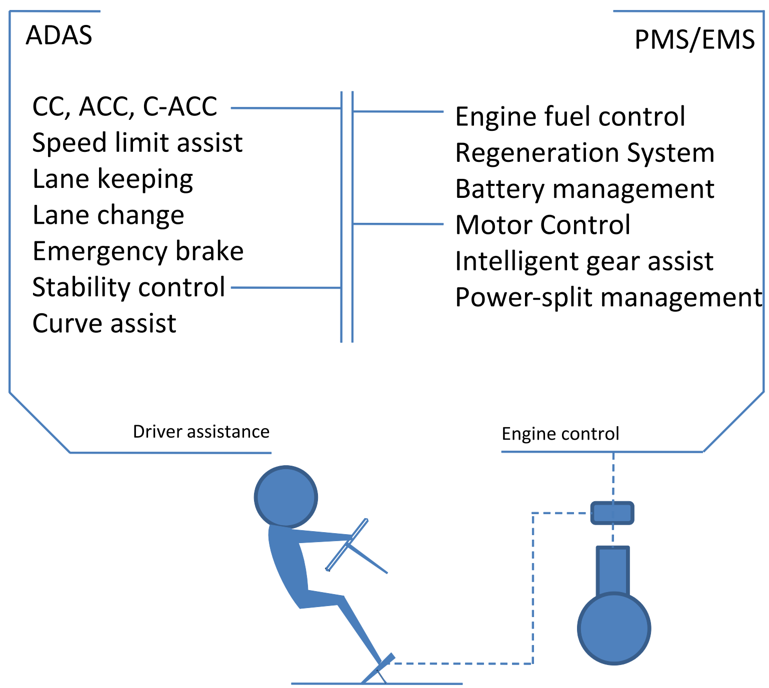
Traditional method

Limited communication between ADAS and energy management systems

Present

Acceptable because advanced functionalities are in development stage

Architecture development is in a transitional state



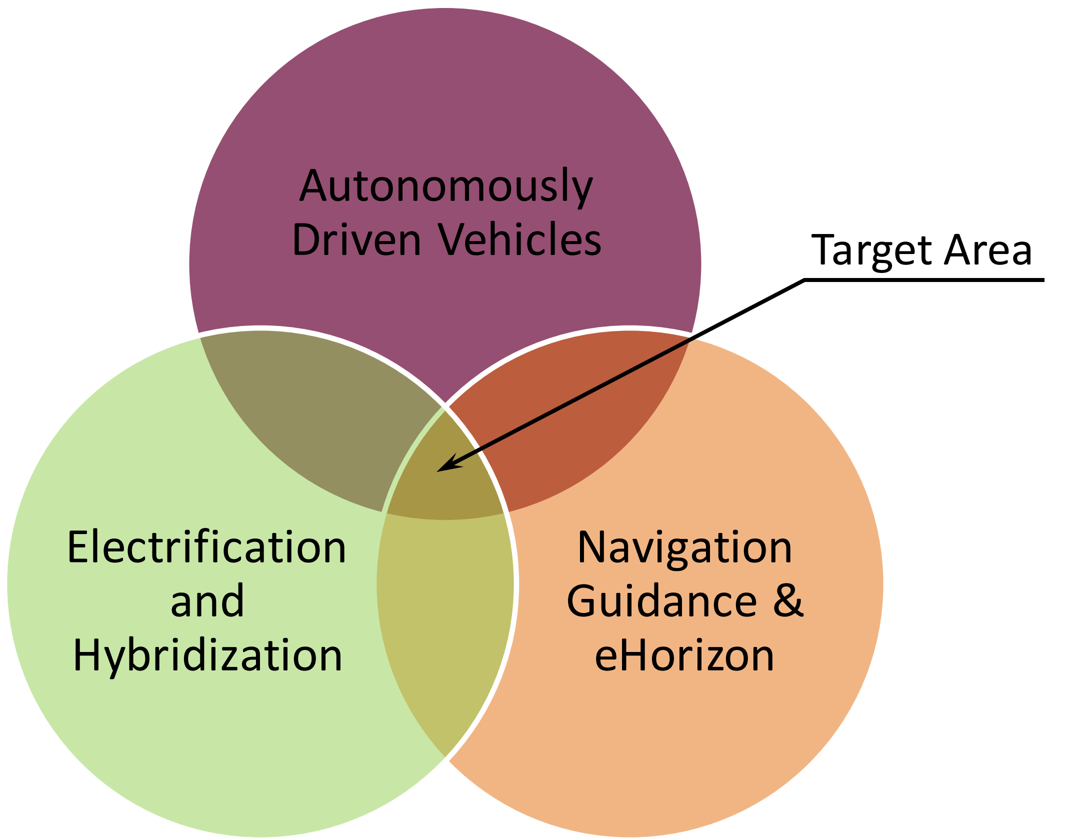
Future

Incompatable

Inadequate

Inherently incapable of supporting and processing incoming environment data

Technologies that will set the prerequisites



Defining properties for the next generation of vehicle controllers

They are already here!

Eco-driving rules

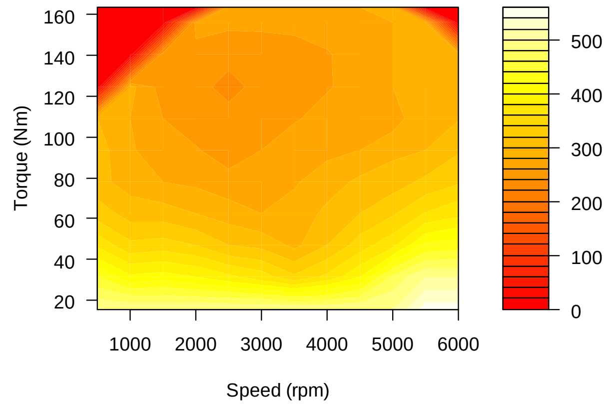
- Ensure proper gear selection
- Shift into a higher gear early
- Leave vehicle in gear when braking
- Maintain a steady speed at highest possible gear
- Look ahead and anticipate traffic flow
- Switch off engine at short stops
- Make use of in-car fuel saving devices such as on-board computers and dynamic navigation to avoid traffic jams

Sources:
http://en.wikipedia.org/wiki/Google_driverless_car
http://vislab.it/automotive/
http://www.darpa.mil/
http://technicity.daimler.com/en/autonomous-driving-in-the-tracks-of-bertha-benz/

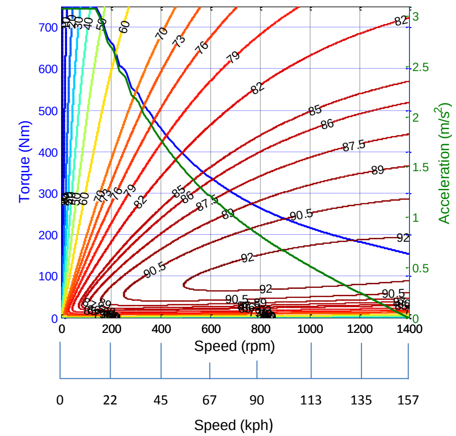
Electrification and Hybridisation

Green Energy

- Serial, Parallel, Power-split hybrids
- Efficiency
- Emissions
- Driving Range
- Component cost
- Oil independence
- BEV HEV PHEV



ICE η= 0-30 %



eMotor η= 70-95 %

Energy density

Oil : 16 km/kg*

Battery: 0.7 km/kg*

*Approximate Estimation

Navigation Guidance & eHorizon

Navigation & Guidance

Approx. Location

Approx. movement properties

ICT Information Communication systems

ITS Intelligent Transportation systems

V2V Vehicle to vehicle communication

V2I Vehicle to infrasture communication

Approaching road conditions

DSRC communication with traffic signals

Beyond Horizon events

Right of space uasge

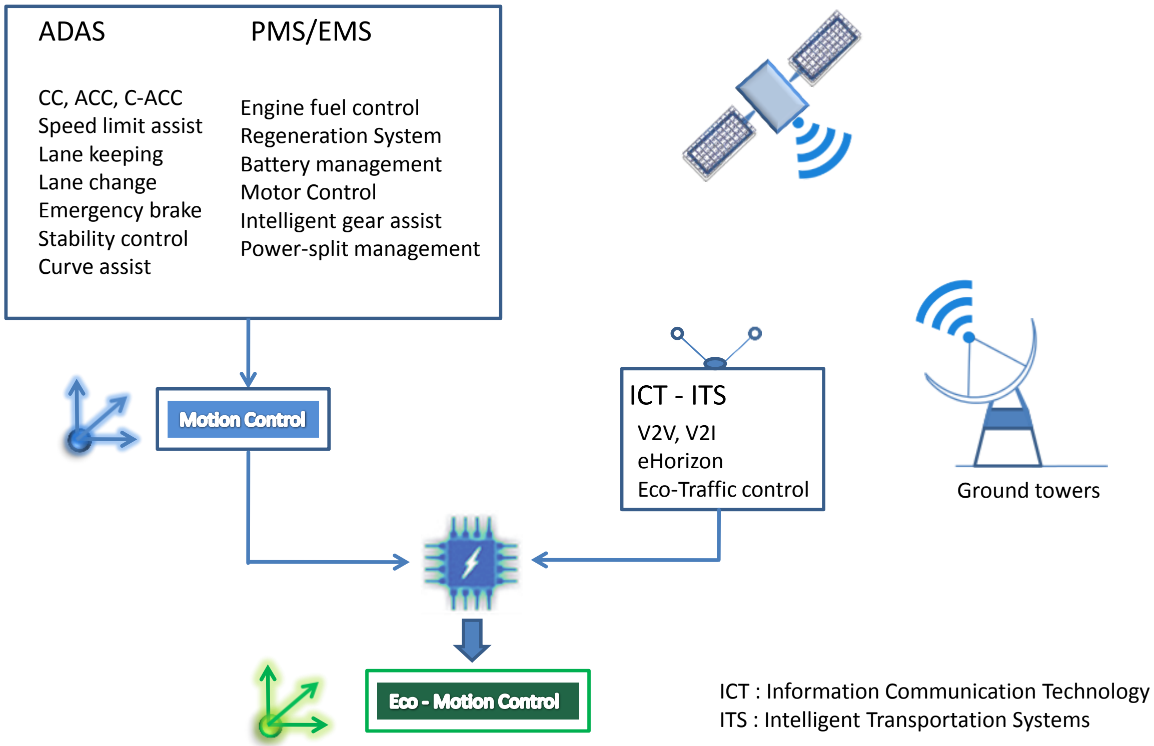
Emergency brake warning

Confirmation for overtaking maneuver

Inevitable collision warning

Vehicle breakdown warning

eco-Motion Control



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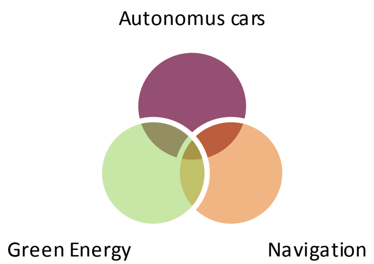
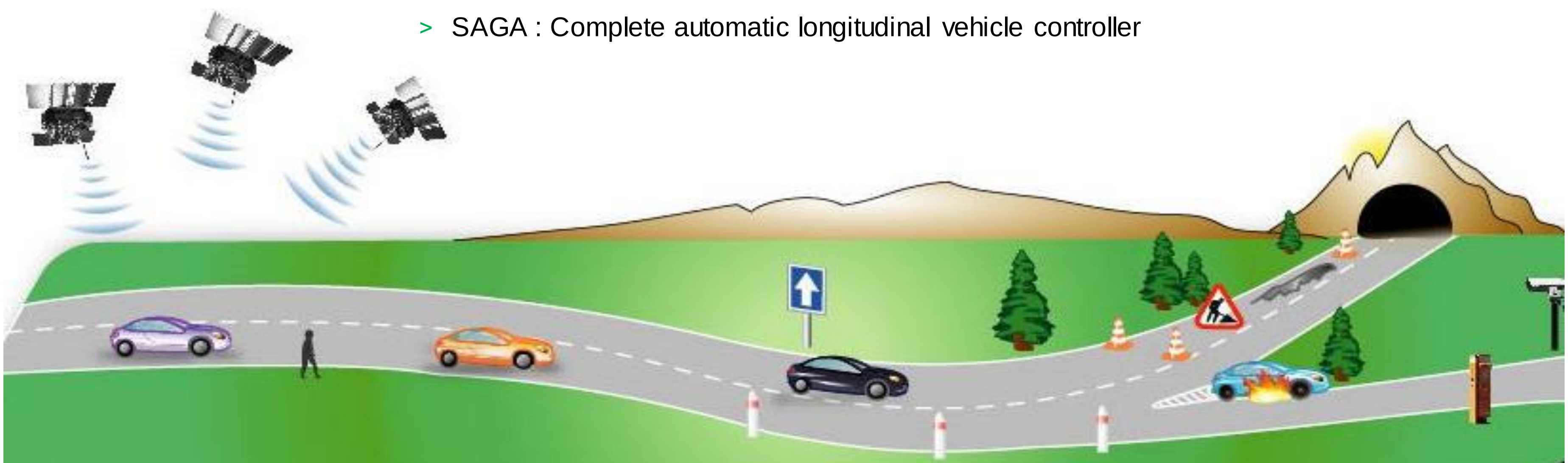
Smart and Green ACC (SAGA)



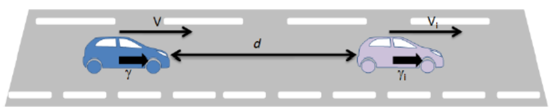
SAGA function is an autonomous longitudinal vehicle motion controller which actively optimizes safety and efficiency

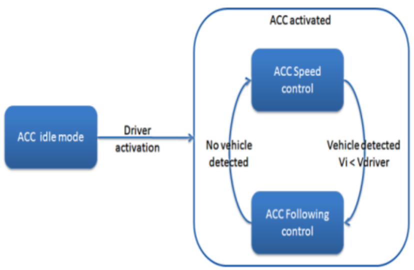
- E-Horizon
- Vehicle position, velocity, altitude, headway spacing…
- Distance to destination, traffic situation, speed limits…
- Gradients, dangerous road curves…
- Energy optimisation and cruise control Green ACC
- SAGA : Complete automatic longitudinal vehicle controller



SAGA concept and applications

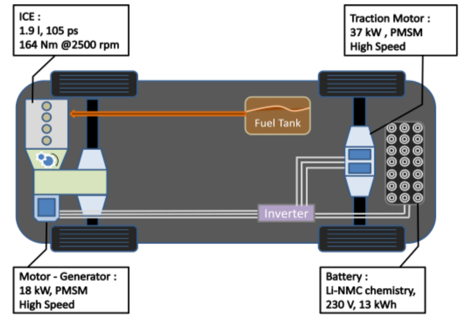
Following Headway: 2 s   Sensor range: 150 m



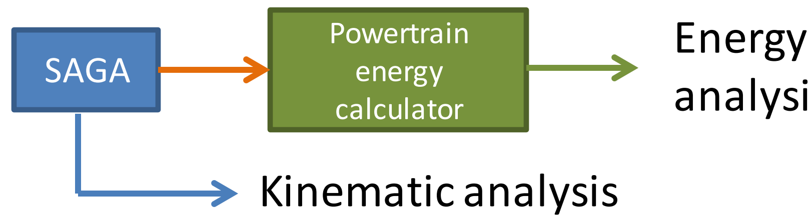


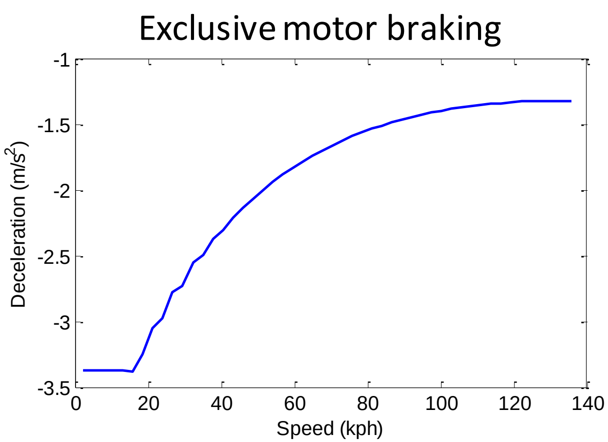
Speed control :
Acceleration: proportional control
Deceleration: SAGA regulated

ACC following:
Acceleration: front vehicle controlled
Deceleration: SAGA regulated
D_sens: 150 m
Safe Headway: 2s



Through the road (TtR)
HEV : 7 kWh
PHEV : 13 kWh
1550 kg Hybrid
1350 kg Conventional





City driving: Motor braking sufficient
Small energy packets available for regeneration
50 kph to 0 kph -approaching traffic signal

Highway driving:
Motor braking insufficient (optimization required)
Attarctive maneuvers for energy recuperation

Approaching slow moving vehicle
Approaching speed limits
Approaching a curve

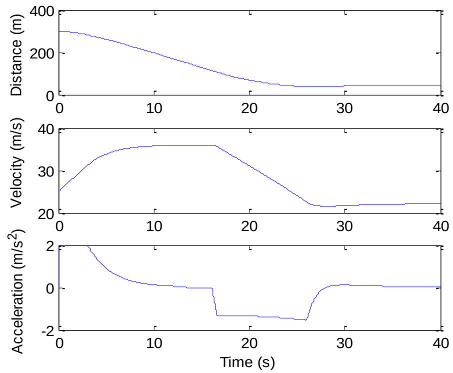
Smart and Green ACC: Results and Strategies

SAGA deceleration 130 - 80 kph, pure motor braking
Sensing distance = 150 m, safe headway 2 s

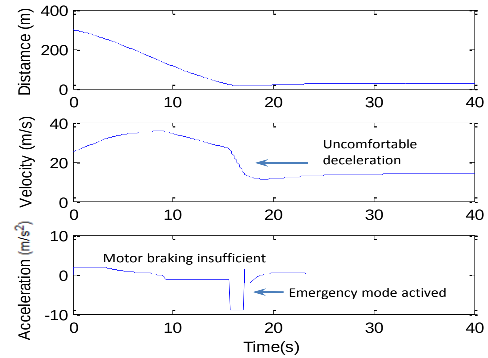
Headway distance

Ego vehicle velocity

Ego vehicle Acceleration



SAGA deceleration 130 - 50 kph, threshold braking, emergency mode below 1.5s



Threshold braking

Use motor brake exclusively

If headway falls below 1.5 s apply emergency brakes

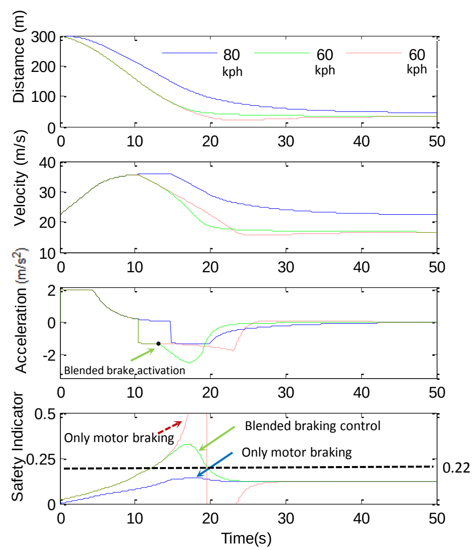
Blended braking

130 kph – 80/60 kph

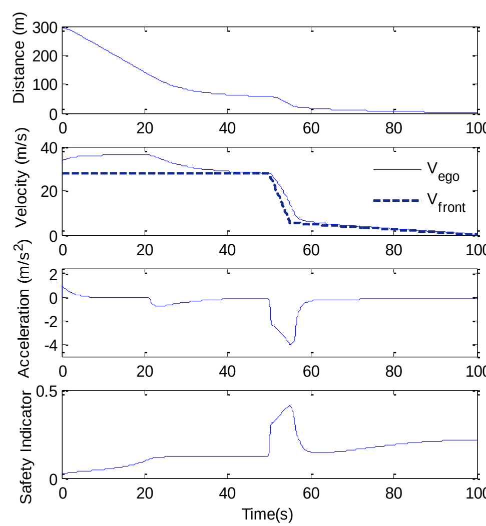
Use motor brake exclusively at entry

Constantly evaluate the safety status with Safety Indicator (S.I.)

At S.I. limit of 0.22 supply excess deceleration by blending motor and conventional braking



SAGA deceleration, sudden front vehicle braking



Blended braking strategy test for sudden deceleration of front vehicle

Speed equalisation @ 100 kph

Front vehicle decelerates intensively till 30 kph in 5 s

SAGA successfully manages the maneuver without compromising safety

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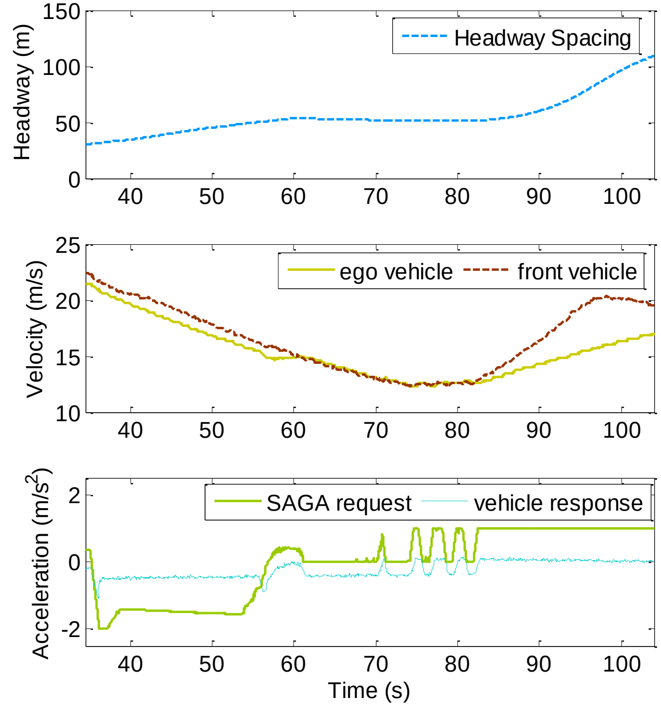
Smart and Green ACC: Testing (eFuture project)



Demostrated the functional behaviour of SAGA system

- Front vehicle detected
- Deceleration command
- Following mode

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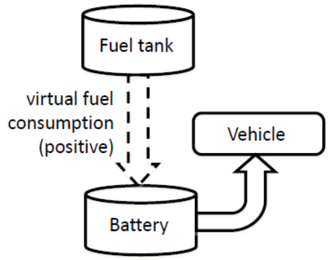
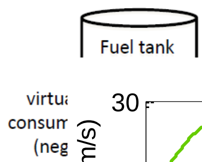
ECMS: Equivalent Consumption Minimisation Strategy

- ✓ zero energy variation of the battery along driving cycle
- ✓ all energy ultimately comes from fuel
- ✓ use of the battery means future ("virtual") fuel consumption





Source :
Optimal Energy Management of Hybrid Electric Vehicles: 15 years of development at The Ohio S

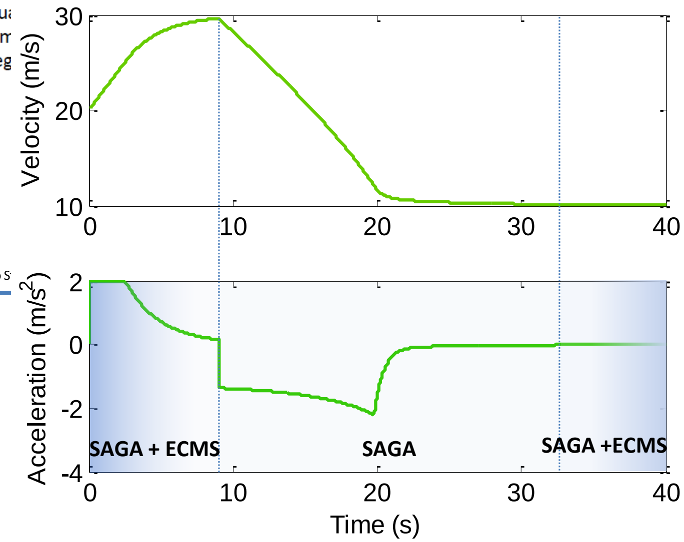
The Equivalence Ratio

$$s(t) = E_{fuel} / E_{elec}$$

$s(t)$ is a conversion factor

ergy

uel



- The trick is –
  - To discharge the battery at worse engine efficiencies and replace the engine power
  - To charge the battery at best engine efficiency

$$E_{total} = E_{ice} + E_{batt}$$

$$\dot{m}_{fuel} = \dot{m}_{ice} + s(t) \cdot \dot{m}_{batt}$$

$$\dot{m}_{fuel} = \dot{m}_{ice} + s(t) \cdot \frac{E_{batt}}{Q_{lhv}} \cdot s\dot{o}c(t)$$

$$\dot{m}_{fuel} = \dot{m}_{ice} + s(t) \cdot \frac{P_{eM}}{Q_{lhv}}$$

$$P_{ice.min} \leq P_{ice}(t) \leq P_{ice.max}$$

$$P_{eM.min} \leq P_{eM}(t) \leq P_{eM.max}$$

$$P_{gen.min} \leq P_{gen}(t) \leq P_{gen.max}$$

$$SOC_{min} \leq SOC_{batt}(t) \leq SOC_{max}$$

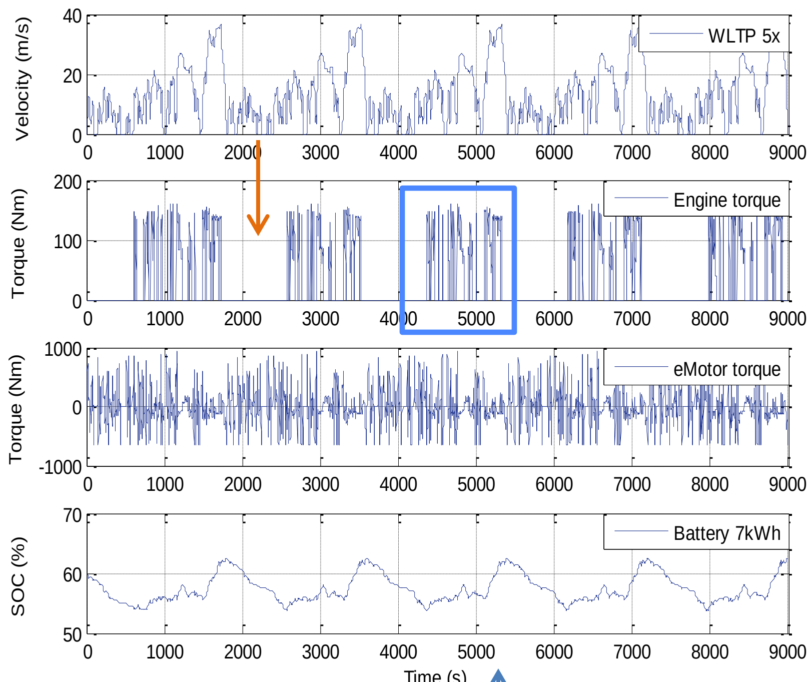
- The Problem is –
  - Future efficiencies or operating points cannot be known. So we have to assume average efficiencies

ECMS: SOC regulation and controller behaviour

SOC regulation:
HEV with 7 kWh battery
Charge sustaining

$$s(t) = s_0 + s_0 \cdot K \cdot \tan\left(\frac{soc_{ref} - soc(t)}{2\pi}\right)$$

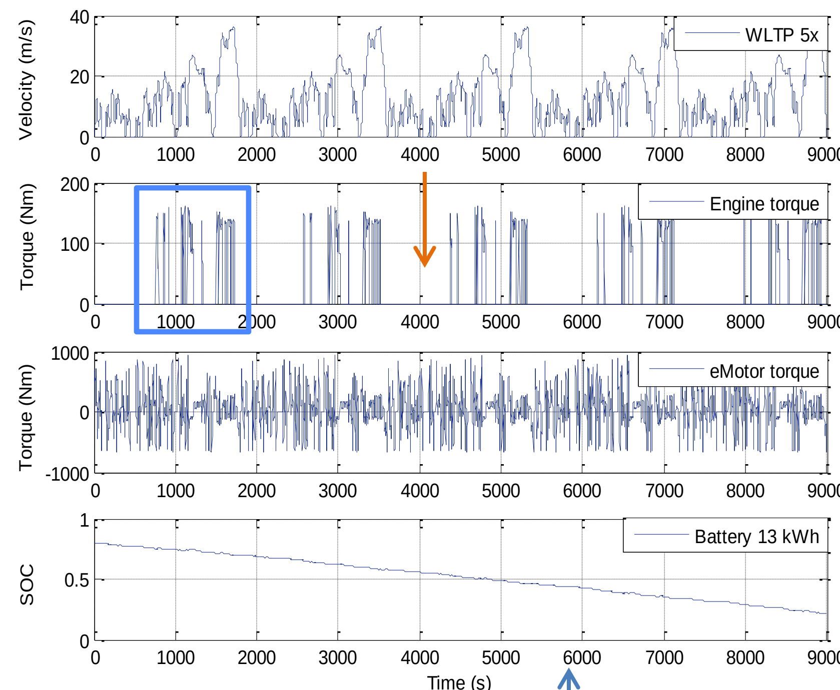
WLTP: Worldwide harmonized Light vehicles Test Procedures



SOC regulation

SOC regulation with SOC_{ref} adaptation:
PHEV with 13 kWh battery
Charge depleting

$$soc_{ref(t)} = \left(\frac{soc_{final} - soc_{init}}{D_{total}}\right) \cdot d(t) + soc_{init}$$



SOC optimised depletion

Travel distance known

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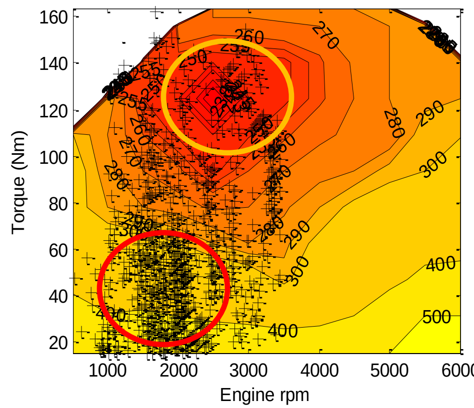
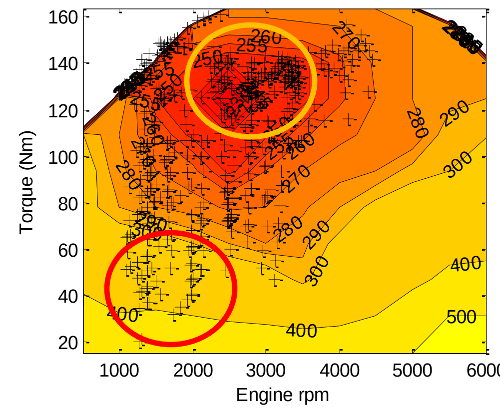
ECMS: SOC regulation and controller behaviour

ECMS actively transfers engine operating points from low effciency region to high effciency region



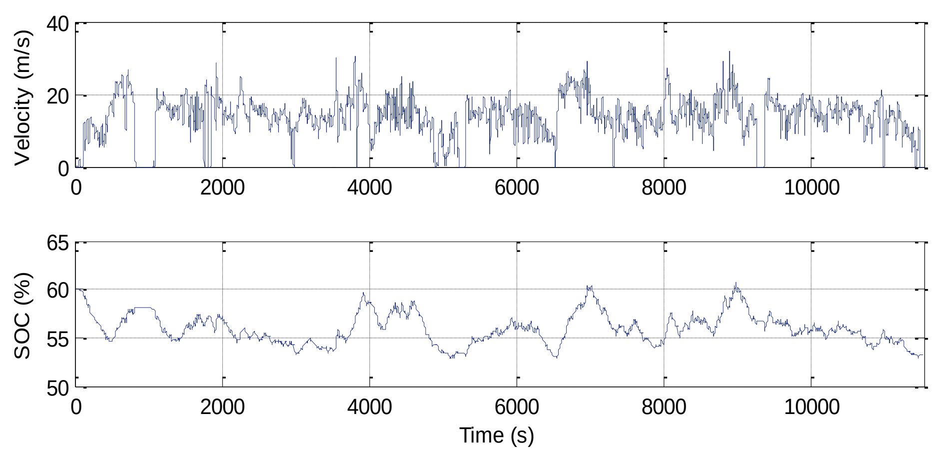
Engine operating points, **conventional vehicle** over WLTP cycle



Engine operating points, **HEV with ECMS** over WLTP cycle

ECMS controller behaviour on a random set of velocity points

At end of a **157 km, 13000 s** trip the SOC is still maintained near the set reference



ECMS applied on real world recorded velocity values

(Arco_Merano drive, Ecosm 2012)

Energy analysis

Fuel Consumption for Various Powertrain Configurations

Velocity Cycle	Powertrain topology	Consumption (litres/100km)
WLTP class3 (5x)	Conventional ICE	6.68
WLTP class3 (5x)	Pure HEV (CS)	5.52
WLTP class3 (5x)	Plug-in HEV (Blended)	3.23
Real world (A_M)	Conventional ICE	5.54
Real world (A_M)	Pure HEV (CS)	4.19
Real world (A_M)	Plug-in HEV (Blended)	1.96

ECMS (HEV) vs ICE (conventional)

18% saving

24% saving

Energy Recovery Potential for Various Maneuvers

Braking Maneuver	Recovered Energy (Wh)	K.E depletion (Wh)	Time (sec)
140 – 80 kph	130	243	14
130 – 80 kph	100	174	10
140 – 100 kph	70	159	8
100 – 60 kph	57	106	9
50 – 0 kph	24	41	6

Kinetic energy lost : 243 Wh
Air drag portion : 57 Wh
Wheel Resistance : 28 Wh
Remaining : 158 Wh
Recovered : 130 Wh
Efficiency : 81%

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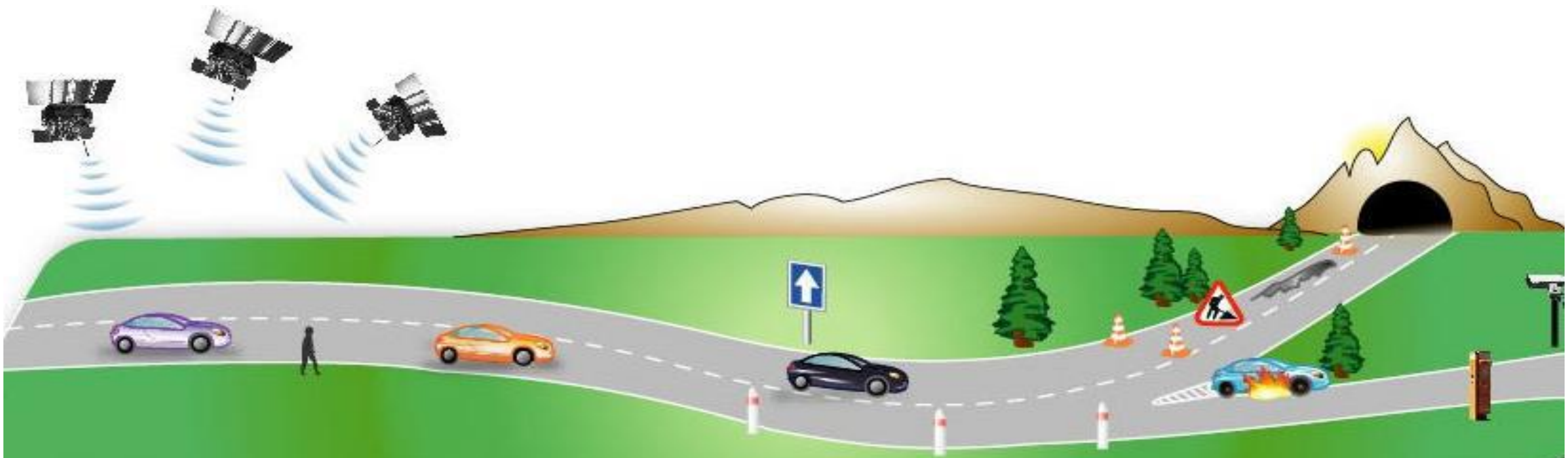
Thank you!

Questions?



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