

Online prediction of battery electric vehicle energy consumption

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Where innovation starts

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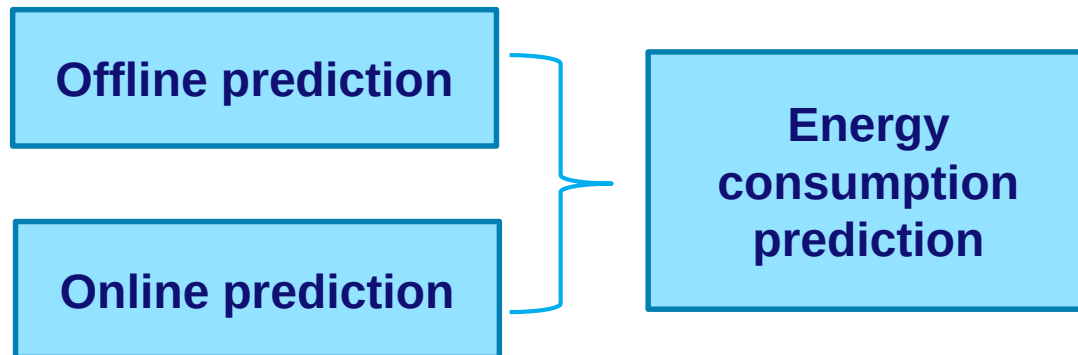
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Introduction

Limitations of BEVs:

- High initial cost
- Limited driving range
- Long charging time
- Availability charging stations?



Introduction

Test vehicle: TU/e Lupo EL

- Electric vehicle built by TU/e
- Donor vehicle: VW Lupo 3L
- Vehicle mass: 1060 kg
- Battery capacity: 27 kWh
- Top speed: 130 km/h
- Road legal since 2011

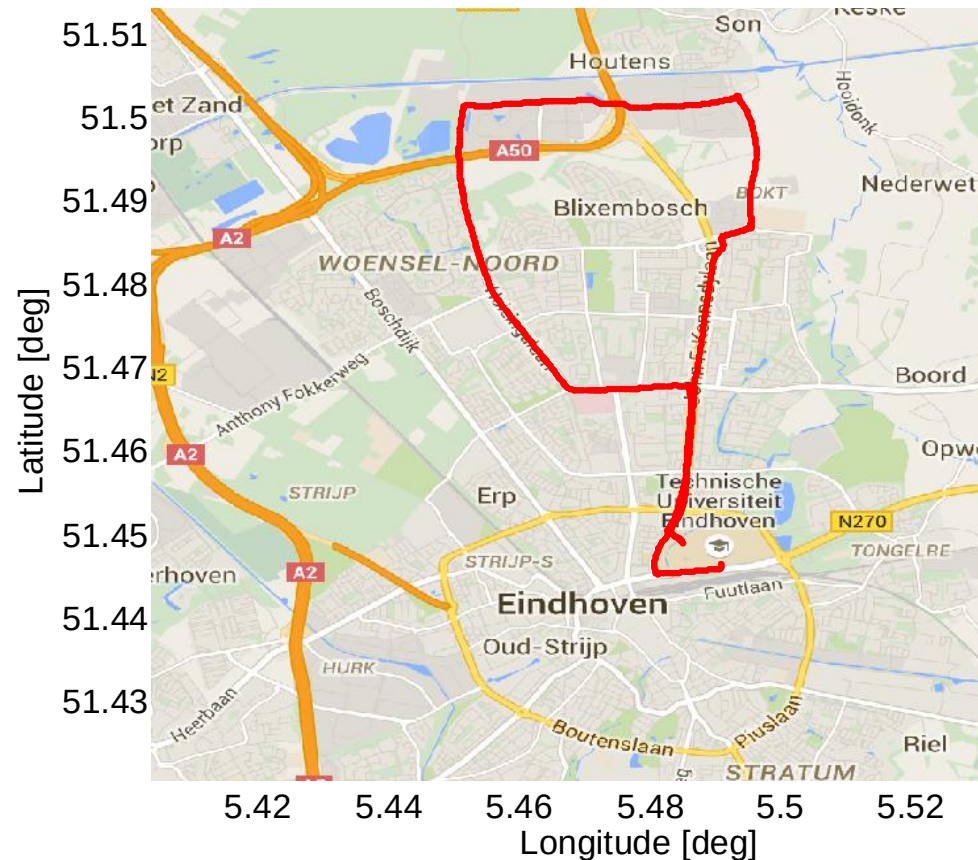
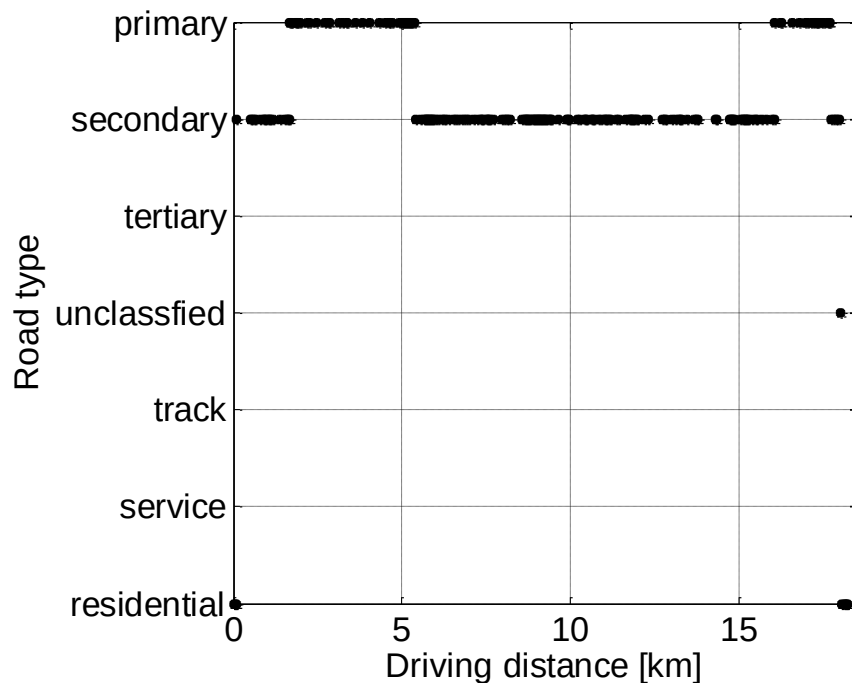


Offline energy consumption prediction

Reference: J. Wang, et.al., Electric vehicle energy consumption modeling and prediction based on road information. In EVS28, KINTEX, Korea, May 2015.

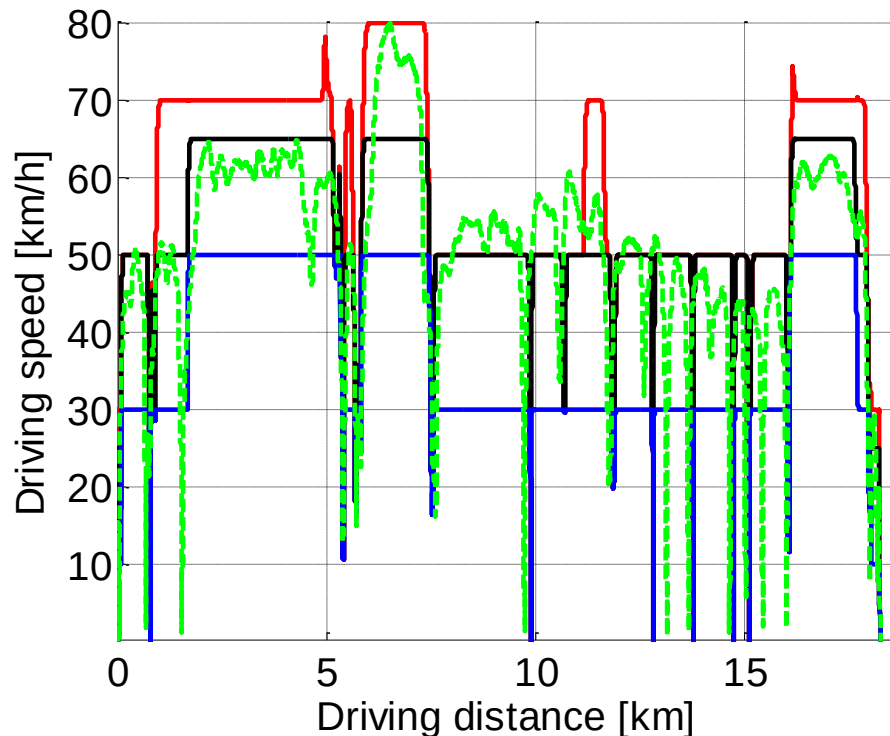
Rural driving as an example:

Distance: 18 km, Traffic lights: 14

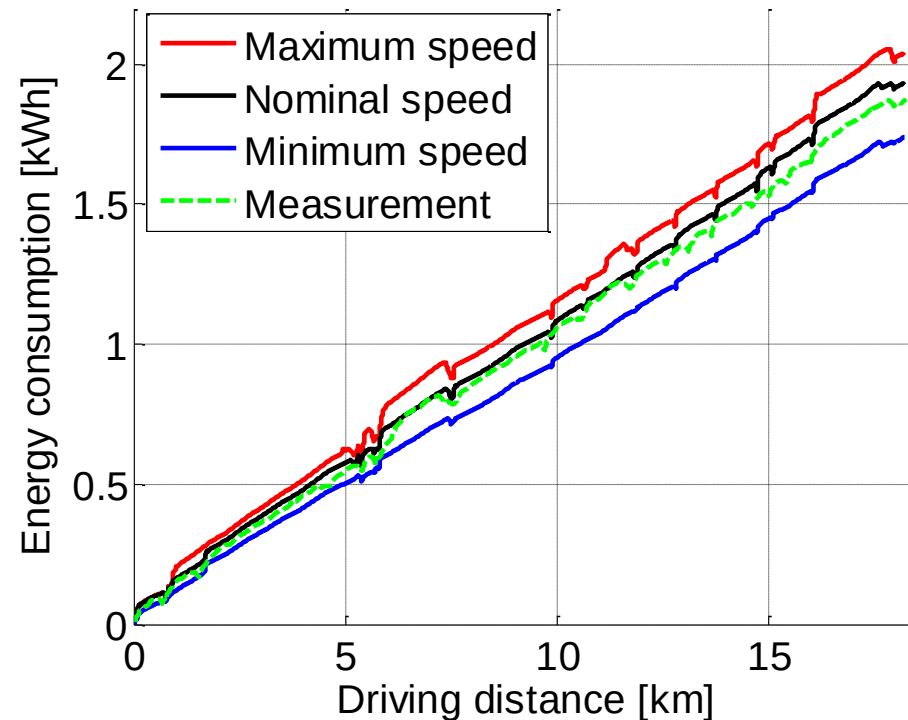


Offline energy consumption prediction

Three predicted speed profiles:
Maximum, nominal and minimum speed.

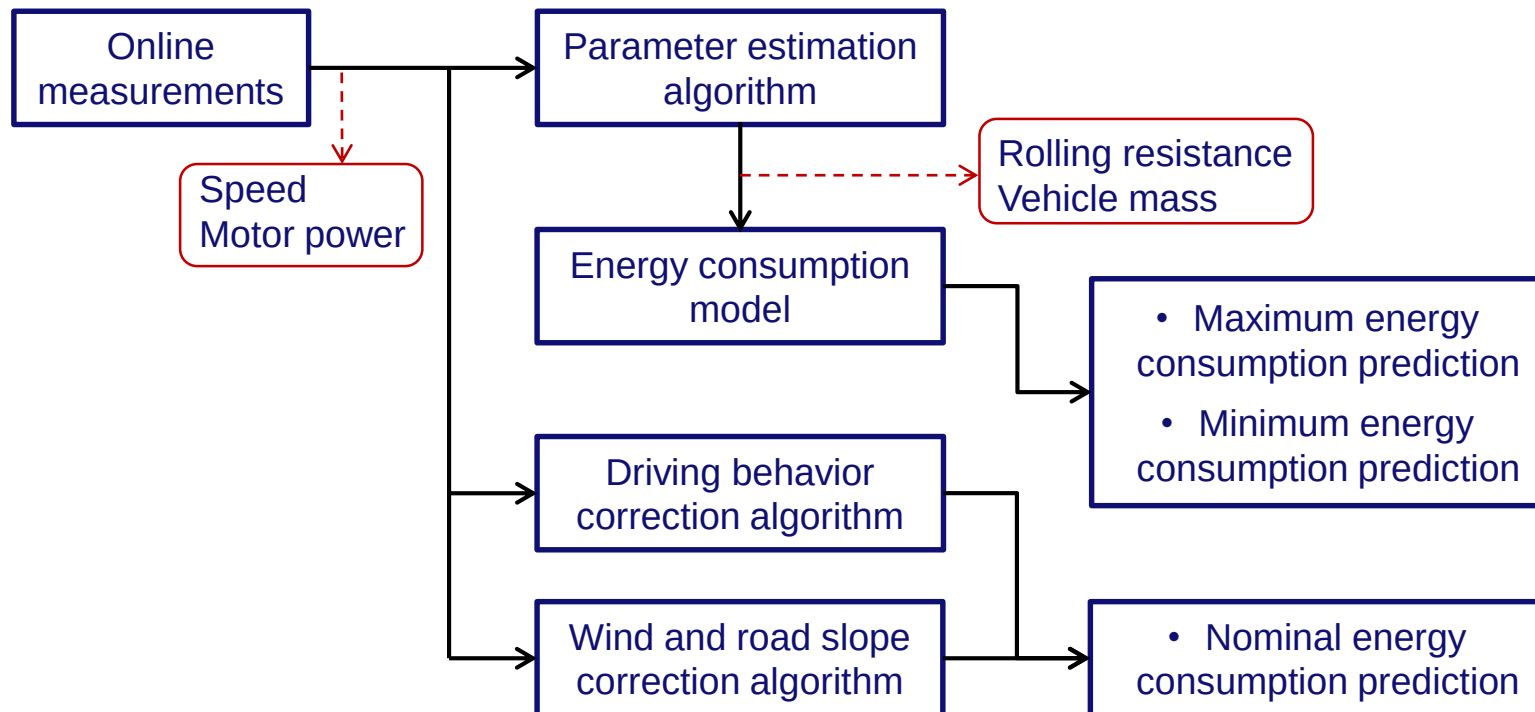


Energy consumption prediction



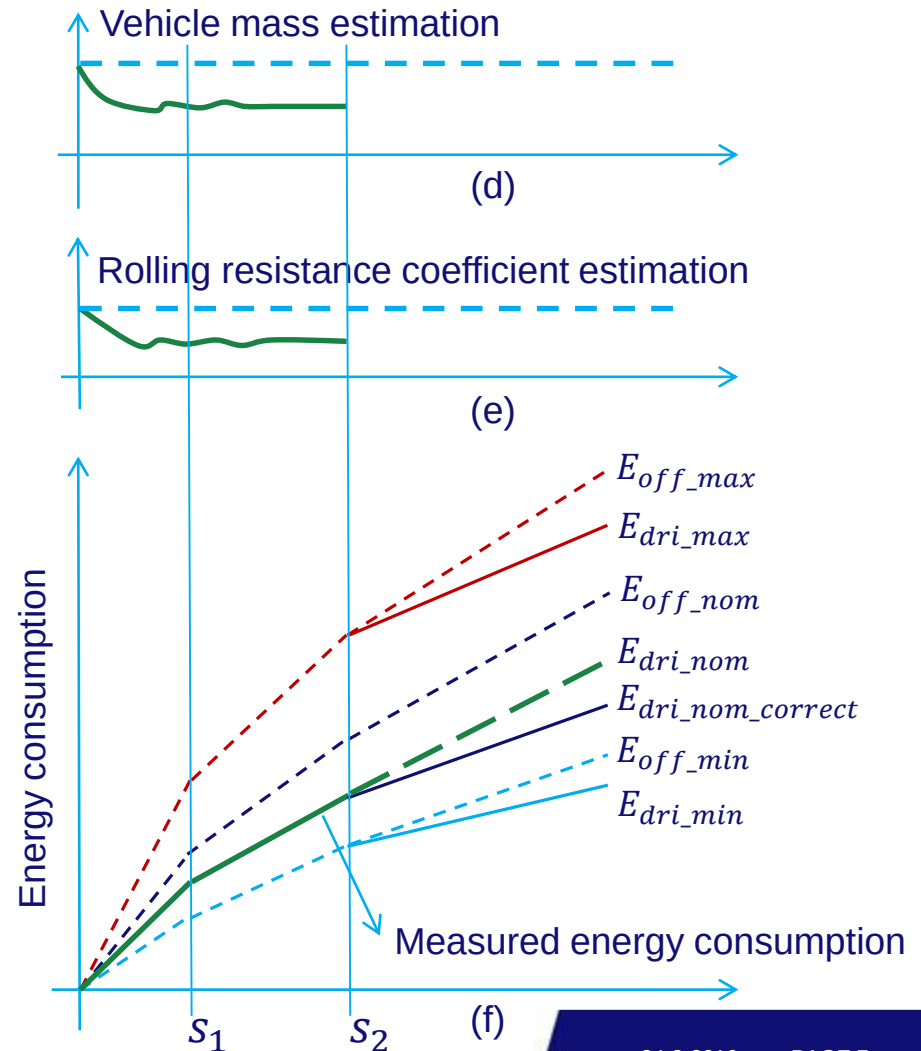
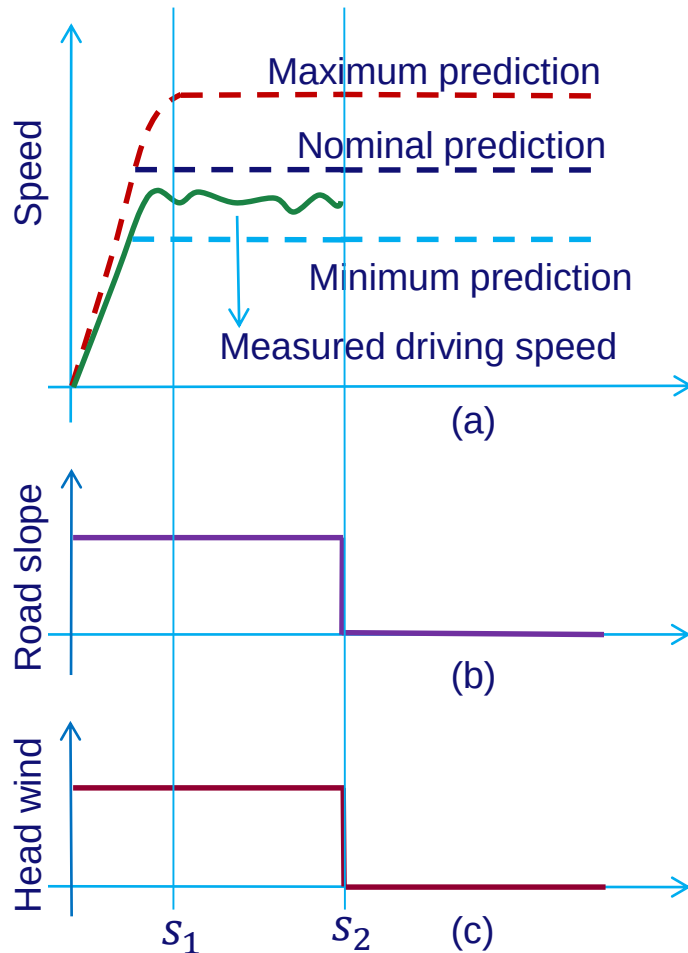
Online energy consumption prediction

Online algorithm structure



Online energy consumption prediction

Online algorithm structure



Online energy consumption prediction

Vehicle mass and rolling resistance estimation

Recursive least squares estimation algorithm:

$$P_m = T \cdot \omega = (F_r + F_{aero} + F_g + F_m + F_{fr}) \cdot v$$

Linear format: $y = \varphi^T \theta$

$$y = T\omega - (F_{aero} + (\frac{4 \cdot J_w}{r^2} + \frac{J_m i_g^2}{r^2})a_x + F_{fr})v$$

$$\varphi = \begin{bmatrix} g \cos(\alpha) v \\ g \sin(\alpha) v + a_x v \end{bmatrix}$$

$$\theta = \begin{bmatrix} f_r m \\ m \end{bmatrix}$$

Minimize the loss function:

$$V(\hat{\theta}, t) = \frac{1}{2} \sum_{i=1}^t (y(i) - \varphi^T(i) \hat{\theta})^2$$

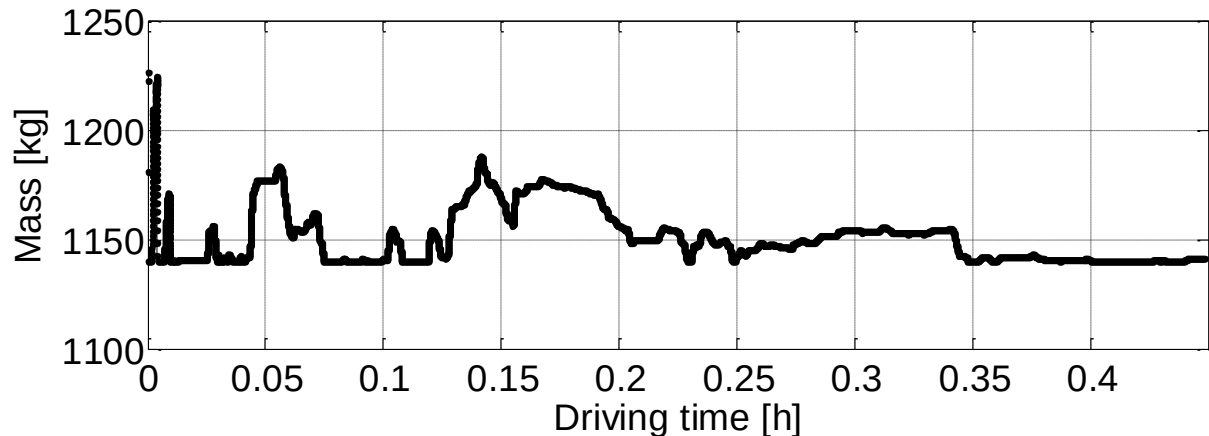
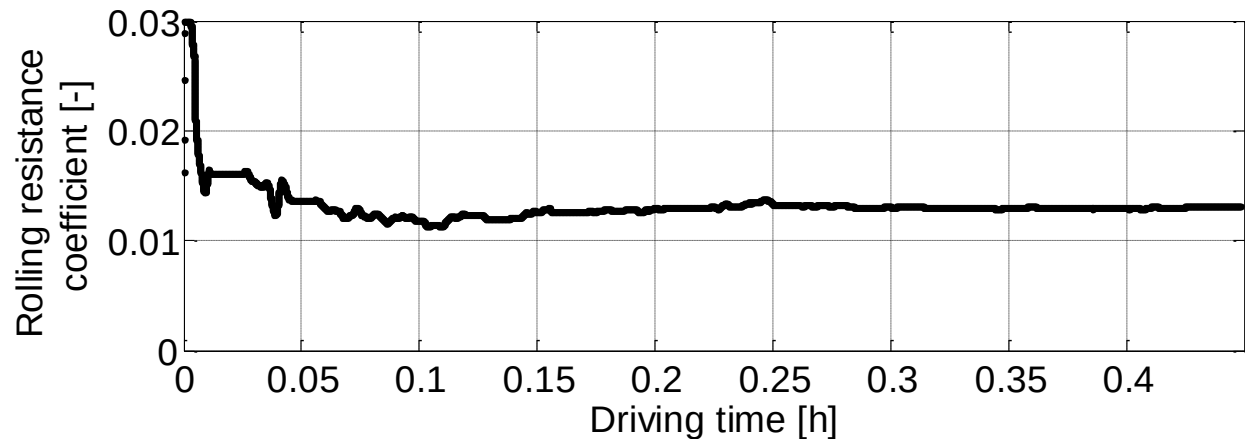
Online energy consumption prediction

Parameter estimation algorithm

Both of estimations are fairly constant after 0.1 h.

The variation of first 0.1 h may be caused by:

- Tyres needing to warm up
- Enough data to converge



Online energy consumption prediction

Driving behavior correction algorithm

Requirements:

- Providing a stable prediction result if the driving behavior is constant.
- Adjust the prediction result timely based on the recent changes in driving behavior.

The main idea of the driving behavior correction algorithm:

$$\bar{E}_{future} \approx \bar{E}_{past}$$

How to define the $\bar{E}_{past}$?

Online energy consumption prediction

Driving behavior correction algorithm

Past energy consumption:

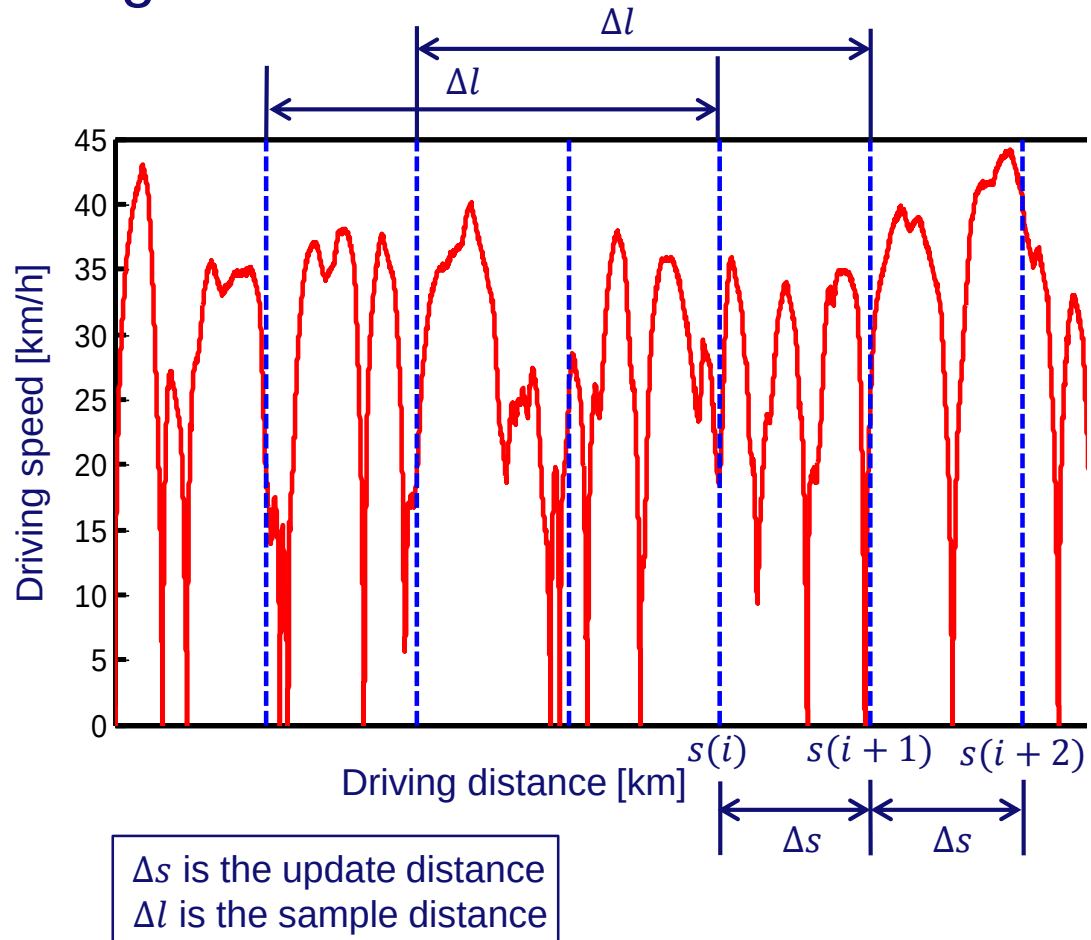
- Short recording, e.g. 1 or 2 km
- Running recording since start
- Long recording, e.g. 500 km

Moving average:

$$\bar{E}_{p:ma}(i) = \frac{E(s(i) + \Delta l) - E(s(i))}{\Delta l}$$

$$s(i + 1) = s(i) + \Delta s$$

Δs : 2 km highway $\Delta l = 3\Delta s$
1 km other types

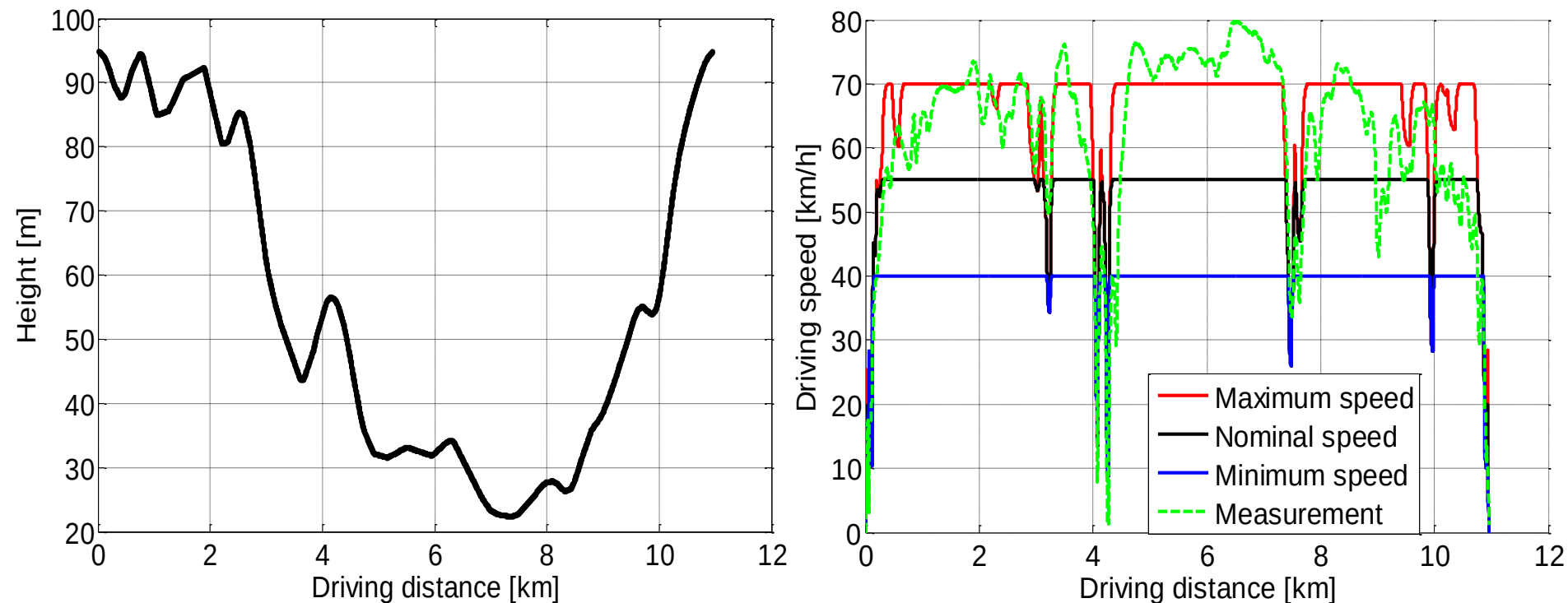


Online energy consumption prediction

Wind and road slope correction algorithm

$$\bar{E}_{future} = \bar{E}_{past} - \bar{E}_{past_(\text{head wind}+\text{road slope})} + \bar{E}_{future_(\text{head wind}+\text{road slope})}$$

One hilly route is shown as an example:



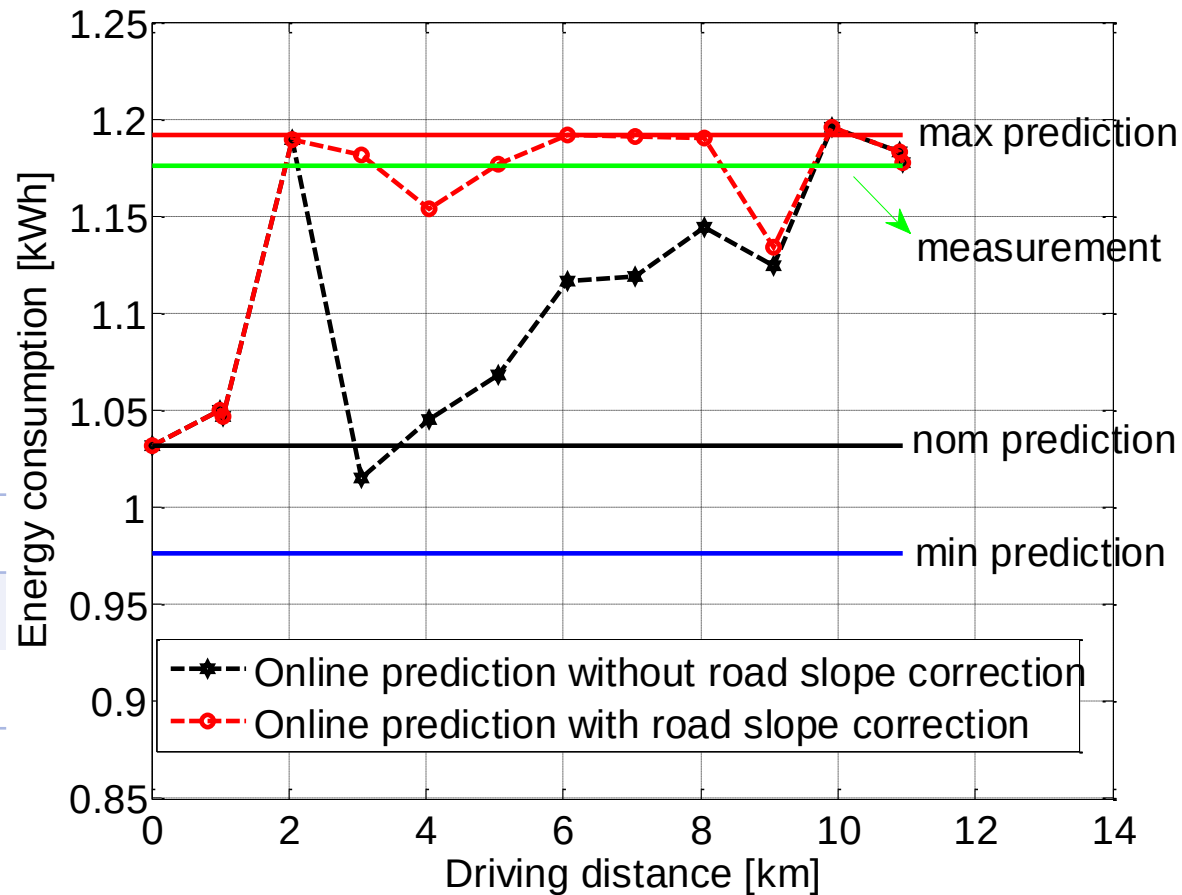
Online energy consumption prediction

Wind and road slope correction algorithm

Evaluation standards:

- MAPE (mean absolute percentage error)
- SDPE (standard deviation percentage error)

	MAPE	SDPE
With slope	3.35	4.50
Without slope	6.37	4.90



Online energy consumption prediction

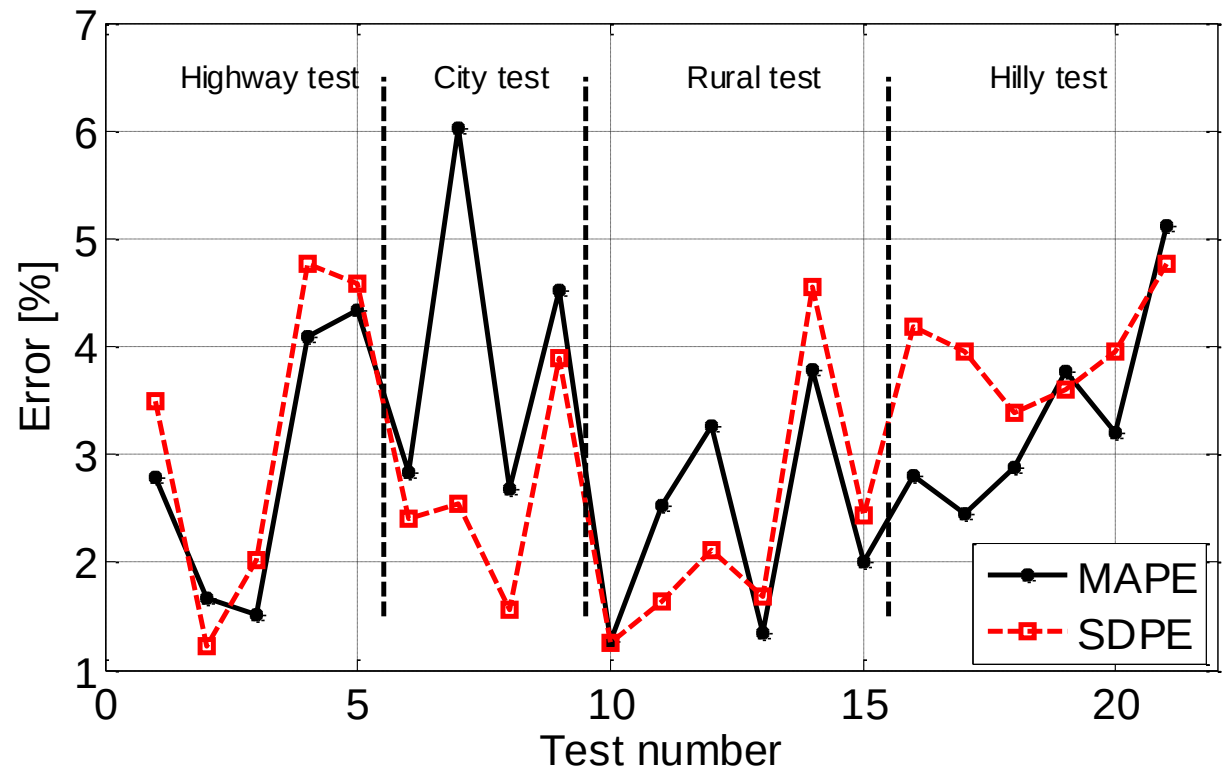
Driving tests verification

21 tests

Temperature: 0-26 deg.C

Range: 5-115 km

Speed: 21-100 km/h



Conclusions and recommendations

Conclusions:

- An online algorithm is designed to adjust the energy consumption prediction during driving. The online algorithm can estimate the vehicle mass and rolling resistance and adjusts the energy consumption prediction based on the current driving behavior.
- 21 driving tests on the public road are used to verify the algorithm. The comparison between the actual energy consumption value and online prediction result shows that the MAPE and SDPE of most tests are within 5% during driving.

Recommendations:

- Real-time traffic information should be considered in future research.

Thank you for your attention

Questions ?