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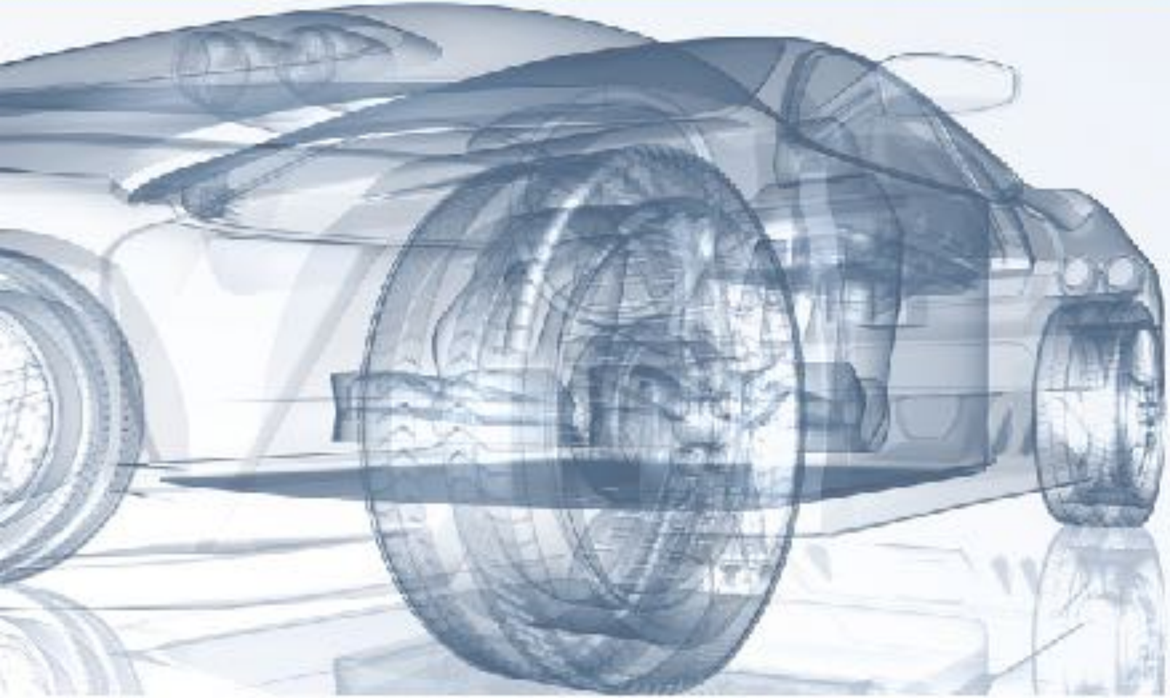

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An intelligent energy management system for an electric bicycle

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Agenda

- Introduction
- Problem definition
- Architecture of system
- Offline EMS
- Online EMS
- Tests
- Conclusions

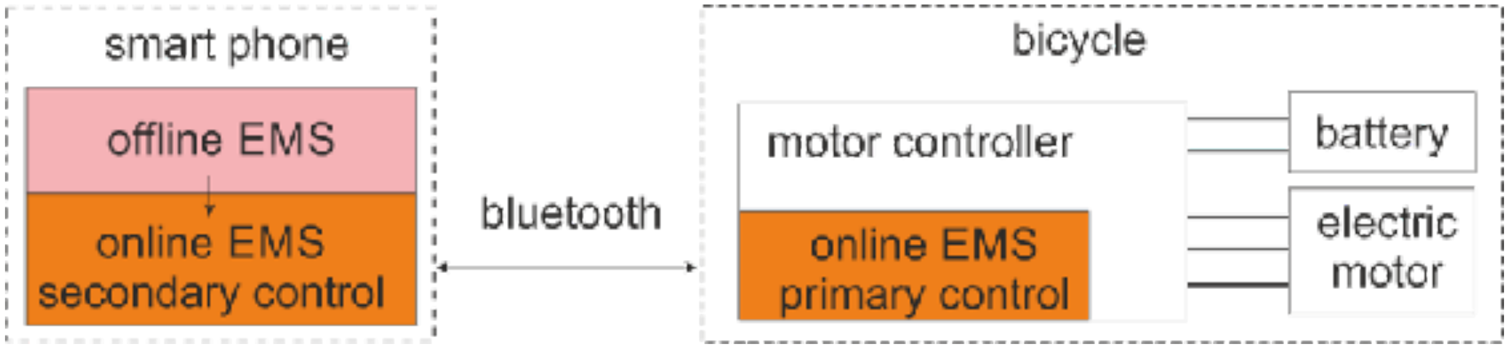
Introduction

- Electric bicycles are in the Netherlands the most widely used (hybrid) LEV's
- The power assist systems are often relatively system
- Route information (length, slope, wind) is not used
- As a consequence, the battery can be depleted before reaching the destination

Problem definition

- Design an "Energy Management System" that calculates the optimal support for a predefined route
- Length, slope and wind at the route are known
- Amount of available energy from the battery is limited
- Optimization criterion: smallest drive time
- Additinal costs to implement EMS must be minimized

Architecture



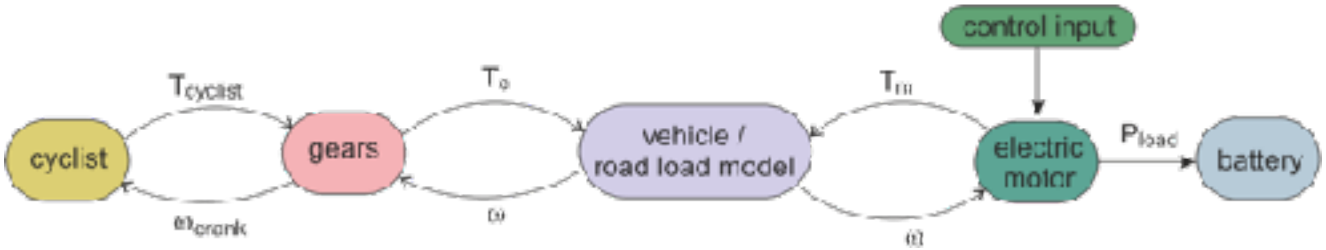
- EMS is coupled to a navigation app that runs on a smart phone
- Wind and slope is obtained from internet
- EMS consists of 2 parts: offline EMS and online EMS
- Additional costs: bluetooth interface on bicycle controller

Offline EMS

Purpose: Calculate assist level that gives the smallest drive time

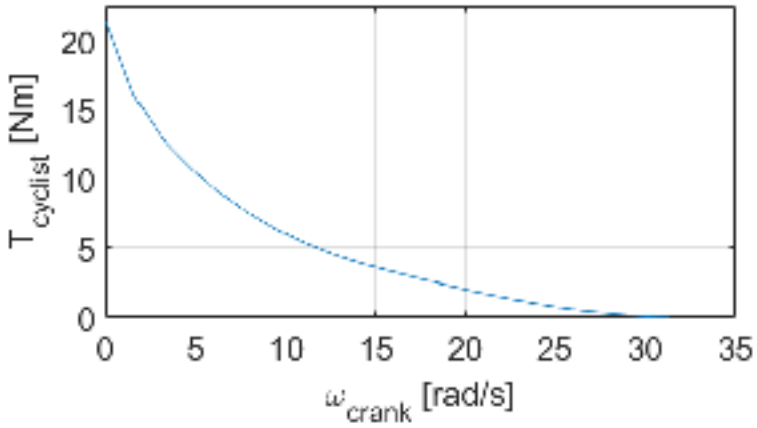
We used a standard bicycle model that includes:

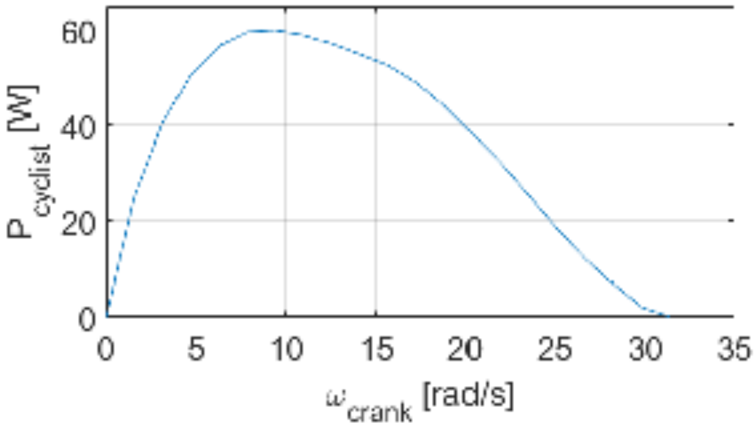
- drag force (depends on wind speed and direction)
- rolling resistance / gravity force
- Motor is modelled by its efficiency map
- Battery is modelled by a voltage source plus internal resistance



Offline EMS

Cyclist model:

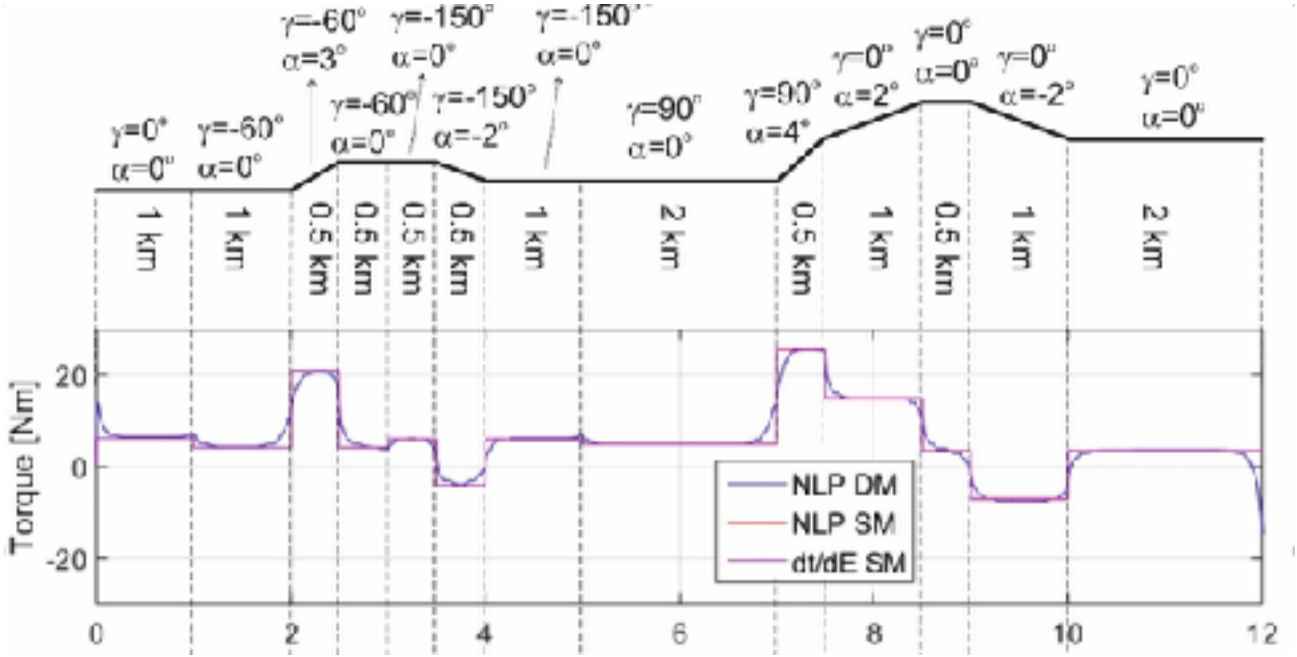




Constraints:
Energy is limited
Speed constraints (legislation)
Power constraints (motor / battery)

Results offline EMS

- Tests on 3 algorithms (DP / NLP / dtdE) on a 12 [km] drive



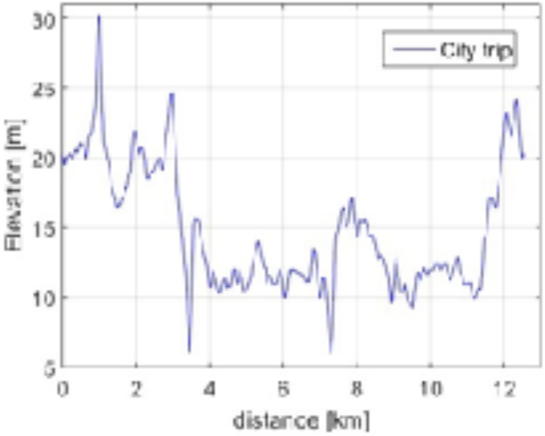
Online EMS

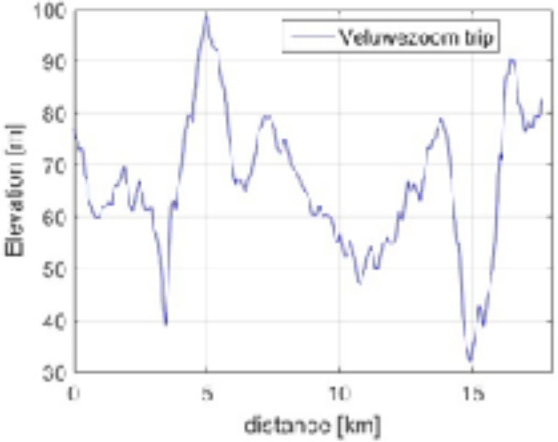
Purpose: Calculate support level to reference values calculated by offline EMS and adjust reference setpoints in case of deviations caused by:

- Traffic situations
- Inaccurate model parameters and disturbances (cyclist power, wind speed)

Tests

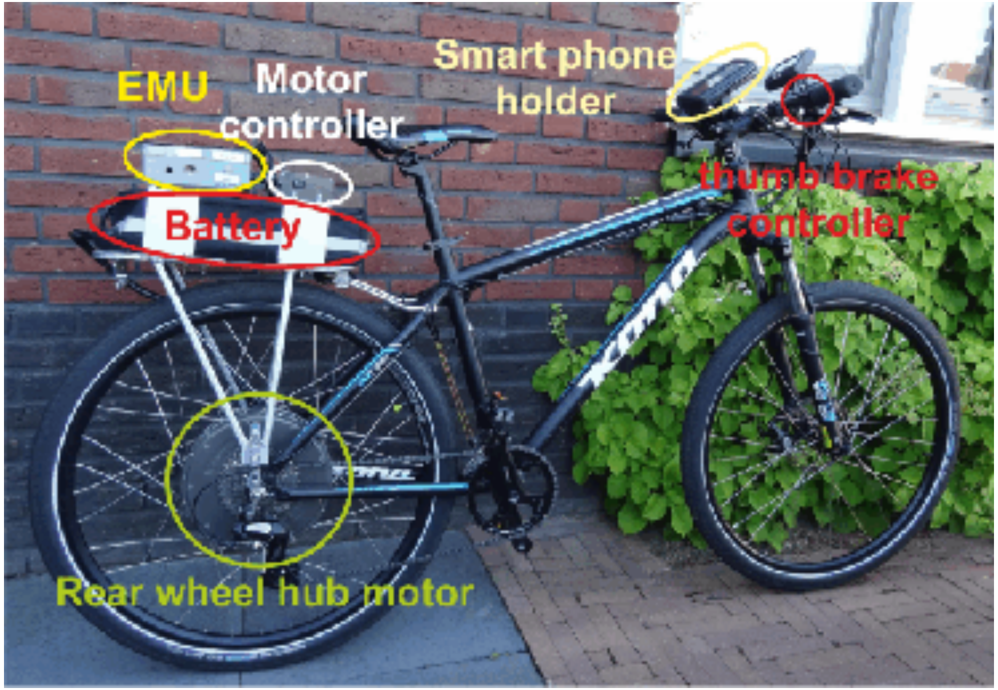
Our EMS is tested on a 18 [km] long recreational route and a 12 [km] long city drive.





Test bicycle:

- All terrain bicyle
- Direct drive rear wheel hub motor
- 48V/20Ah battery
- Thumb brake controller for regenerative braking
- Smart phone holder

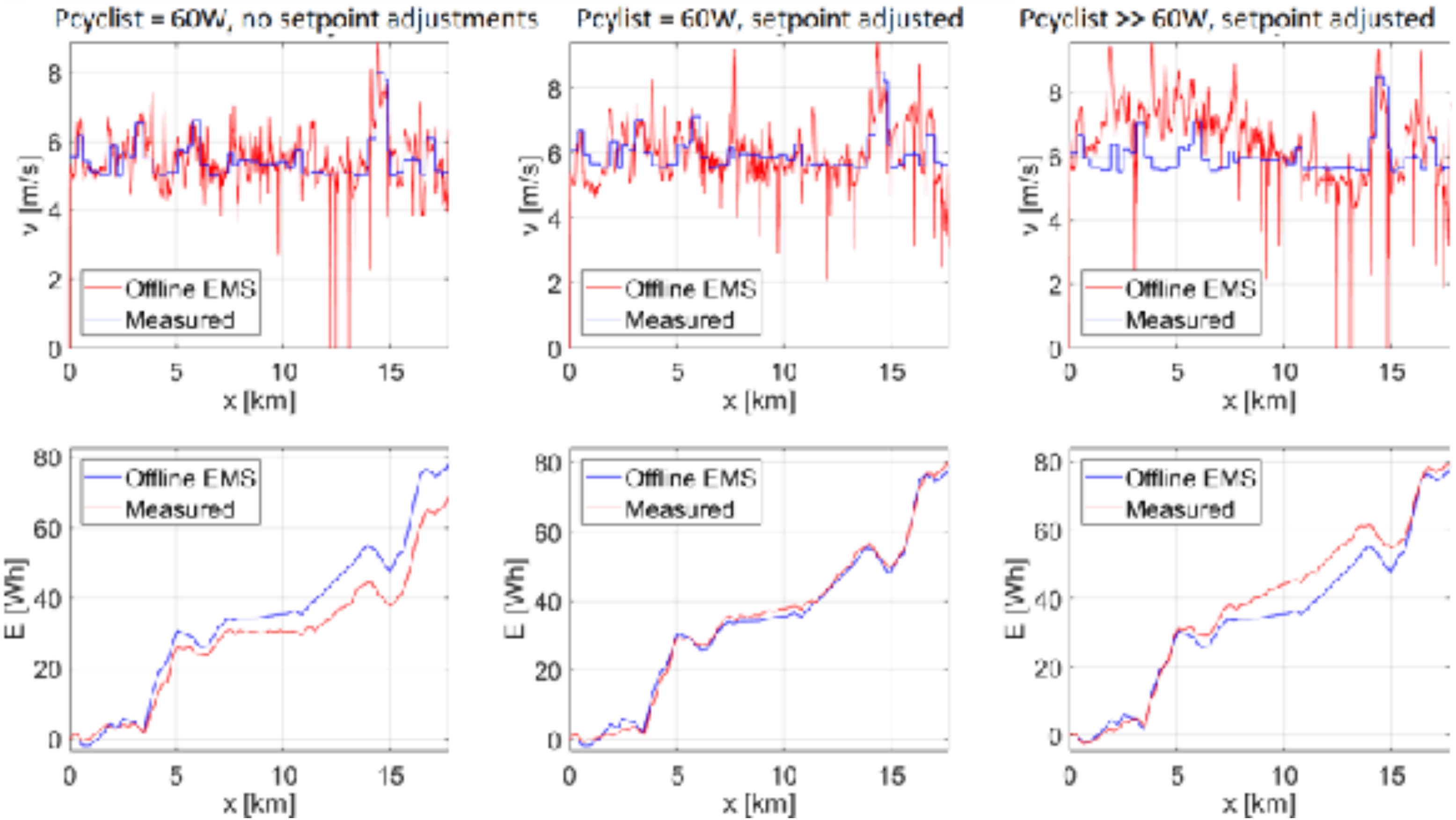


Test conditions

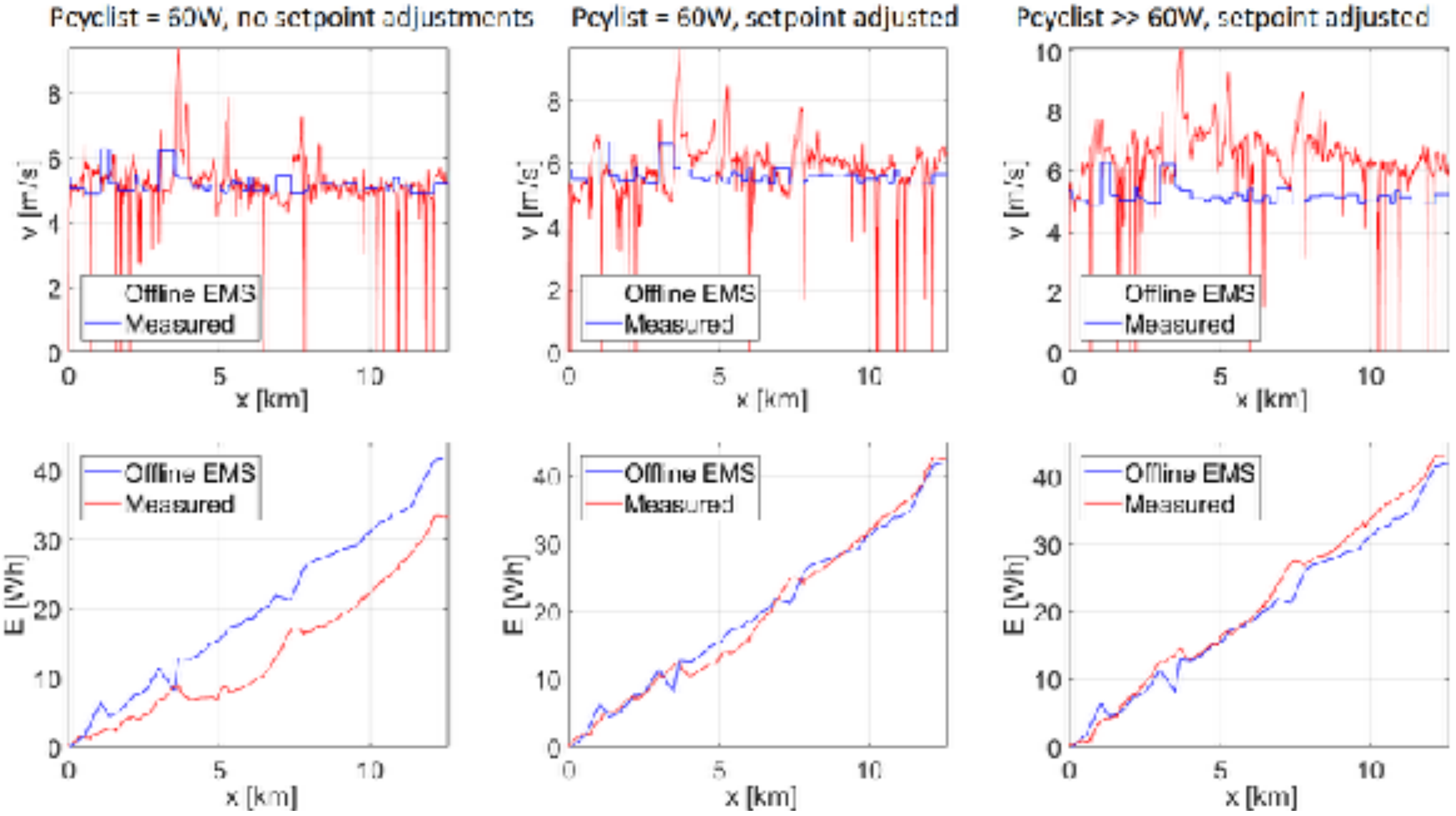
Both routes are tested in the following ways:

1. The cyclist is instructed to deliver on average 60 [W] (same as input of offline system). The online EMS doesn’t correct for disturbances
2. The cyclist is instructed to deliver on average 60 [W] (same as input of offline system). Online EMS corrects the reference setpoints in case of disturbances.
3. Cyclist is instructed to deliver much more than 60 [W] (input of offline system). Online EMS corrects the reference setpoints in case of disturbances.

Test results (recreational trip)



Test results (city drive)



Overview of test results

	Primary control	Pcyclist ≈ 60W	Pcyclist >> 60W
Recreational trip: $E_{offline}$ = 79 [Wh]			
Energy from battery [Wh]	68.8	80.3	80.2
Energy from cyclist [Wh]	57.3	52.7	121.7
Average cyclist power [W]	61.5	62.9	149.2
Regenerative brake energy [Wh]	-24.0	-20.9	-20.7
Percentage of time ems is off [%]	4.2	-	7.0
City trip: $E_{offline}$ = 42 [Wh]			
Energy from battery [Wh]	33.3	42.8	42.9
Energy from cyclist [Wh]	49.4	40.0	67.4
Average cyclist power [W]	63.1	56.2	105.3
Regenerative brake energy [Wh]	-7.9	-7.9	-7.9
Percentage of time ems is off [%]	19.2	-	-

Conclusions

- We succeeded in our main goal to design an EMS that takes route information into account to calculate the optimal support
- The offline EMS is able to estimate the battery energy consumption with an accuracy of 15% if the cyclist power matches to what is inputted in the model
- The online EMS algortihm is able to correct even heavy disturbances
- We used Google maps elevation API to determine the slope. On some points on the route, this service fails (e.g. at bridges or viaducts)
- Some traffic situations require that the cyclist has control over the assist level (e.g. to overtake another road user). This must be implemented yet