SPC-Model

This repository contains a simulink model of a self-propelled-caravan (SPC), an electric caravan designed to extend the range of an EV towing the caravan.

Authors

This model has been made by group SPC-3:

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How to run the model

- Open Matlab
  - the version we used is version R2023a
  - The following Add-Ons are used:
    - Simulink
    - Simscape
    - Simscape-Electrical
    - Simscape-Battery
    - Simscape-Driveline
    - Vehicle Dynamics Blockset
- Run `run_model.m`
  - This initializes all variables and constants required to run the simulation a more detailed explanation can be found below.
- Open `SPC_model.slx`
  - This is the main Simulink-file, which combined all other models.
  - Run the model
  - To view the results open the `Scope` blocks showing the relevant variables.

Simulink model explaination

The main model flow start at the drive-cycle. We use two different drive cycles the first drive cycle is the standart FTP75 drive cycle which is accurately describes inner city driving, or driving around a town. The second drive cycle is artemis, which is a measurement done on a highway. For longer simulations we took the highway measurements and copied it to create a larger dataset useful to simulate an entire battery discharge.

The drive cycle specifies the velocity at a certain time. We feed this velocity into a `Longitudinal Driver` block. This is basically a pre-tunes PID system optimized for a driving cylce and outputs a value between 0 and 1, for both the acceleration and deceleration. These values go into the `motor_PWMController`. There the acceleration value drives a PWM-signal which drives the H-bridge connected to a DC-Motor. The deceleration signal toggles the breaking functionality on the H-bridge, which enable regenerative breaking on the motors. We have not implemented an other breaking system, since this could be handled by the car pulling the caravan. Additionally, regenerative breaking if sufficient most of the time. The DC-motor is connected to a theoretically perfect gear, which is connected to a rotational to linear converter, which has a power output in the forwards direction.

The motor power flows into the `mechanicalbody_model` which simulated the mass of the caravan with it's position and velocity. The caravan is modelled as an intertial point mass, this mass included the actual total mass of the body, but it also includes the rotational interia of the wheels. This is important since the energy pulling on the caravan is partially being converted to rotational momentum and not just translational momentum, which determines the velocity. The `mechanicalbody_model` also includes all other forces acting on the caravan such as the rolling resistance, an optional gravitational force resulting from a slope and finally a simplified version of the drag force. The drag force is modelled as a simple force acting only on the caravan, but in the real world the drag is acting on the combined system of the caravan and the pulling car. To properly model this, computational fluid dynamic(CFD) simulations need to be done, to determine the total drag force on the car and on the caravan seperately, which is beyond the scope of this assignment. By using Simscape to link the movement of the caravan to the motor we automatically receive bi-directional power flow, which is important for features such as regenerative breaking.

The `motor_PWMController` also outputs the motor current, which is directly correlated to the current going through the battery which is simulated in `battery_model` using the built-in `BatteryPack` block. We chose to use this block instead of making a manual model, since this method is more accurate and less time consuming. This models includes charging and the typical voltage curve for Lithium-Ion batteries.

To determine the remaining range and efficiency of the caravan is calculated in the `range_esstimation` model. There the driven distance is gathered from the mechanical model as well as the state of charge. From these values the used charge can be calculated to find the effiecency in km per kWh, which can then in turn be used to calculate the remaining range. So initially the efficiency is set to 1 km/kWh. When the simulation is started the efficiency is updated every hour(simulation time).

Input Variables

Variable	Description
aeroDragCoeff	This constant determines the drag on on the Caravan, A typical caravan has a drag coeffient of 0.45, which is between that of a car and a small bus Source. However, the drag on the caravan is lower, when a car is pulling it.
rollingResistCoeff	The rolling resistance coefficient is determined by the friction in the gearing and in the axle of the wheel. As well as the friction between the wheel and the road.
frontArea	The frontal area of the caravan assuming a width and height of 2m
regen_efficency	How much energy can be stored during regenerative breaking. This value accounts for inefficencies outisde of the internal resistances of the battery and motor
motor_gear_ratio	The motor is connected to the wheels via a fixed gear, this gear ratio can be adjusted here.

Variable	Description
towing_ratio = 1	This variable determines the effective power the caravan needs to supply, a value of 1 assumes zero interaction forces between the car and the caravan (with the exception of turning forces, which are not included in this model), and a value of zero means that the car does all the work. The center of mass(CM) also influences this value, since if the CM is close to the car, the car has to carry more load of the caravan.
massCaravan	The mass of the empty caravan, including the framing and the motor, but not including the batteries
massStorage	The mass of the items people bring with them, such as tent, clothes, pans etc.
nTires	The amount of tires the caravan has. By default we assume one driven axle, therefore, 2 tires in total.
massTire	The mass of a single tire. By default 20 kg Source
radiusTire	default diameter is 17 inches, which converts to 216mm radius Source
rated_speed	Rated maximum speed of the motor. By default 25000 rpm
rated_load	Rated power of the motor, by default 250kW
battery_cut_off	Minimum state of chare(SOC) before the battery cuts off, this limitation is set to prolong the battery lifetime
NominalVoltage	NominalVoltage of the battery. By default we chose 370, which is the result of 100 lithium-ion cells in series
Capacity_Ah	The battery capacity in Ah. By default 300
battEnergyDensity	Energy density of the battery cells. Default is 240 Wh per kg, based on calculations from this source
slope	Average slope during the whole trip in degrees, to make it a slope-profile instead of a constant value, the simulink block needs to be change

Other variables and constants, such as the mass of the battery, the intertia of the tires and the total mass are calculated from the above described variables.

Output parameters

Parameter	Description
Motor Current	This shows the current in the motor which can either be positive(driving) or negative(regenerative braking)
Motor Voltage	Shows the voltage needed to supply the motor
Battery Current	The current drawn from the battery. The current in the motor is the same as the one in the battery.
Battery Voltage	The voltage on the battery terminals

Parameter	Description
Battery SOC	The state-of-charge of the battery
SPC velocity	The velocity of the caravan that tracks the velocity of the car
SPC efficiency	The efficiency of the electric caravn in km/kWh
Remaining capacity	The remaining capacity of the battery in kWh
Remaining driving range	The remaining dricing range of the SPC
Traveled distance	The driven distance

Influence of parameters

Variable					
aeroDragCoeff	0.12	0.15	0.18	2.1	2.4
→ Range	430 km	385 km	365 km	325 km	300 km
rollingResistCoeff	0.004	0.006	0.008	0.01	0.012
→ Range	560 km	440 km	365 km	295 km	260 km
frontArea	2 m2	2.5 m2	3 m2	3.5 m2	4 m2
→ Range	430 km	388 km	365 km	327 km	302 km
regen_efficency	0	0.25	0.5	0.75	1
→ Range	127 km	165 km	200 km	266 km	365 km
towing_ratio = 1	0.5	0.65	0.8	1	
→ Range	925 km	715 km	447 km	365 km	
massSPC	600 kg	700 kg	800 kg	900 kg	1000 kg
→ Range	510 km	440 km	387 km	352 km	365 km
Capacity_Ah	250 Ah	300 Ah	350 Ah	400 Ah	450 Ah
→ Range	260 km	312 km	365 km	486 km	547 km
slope	0	0.3	0.6	1	
→ Range	365 km	140 km	100 km	80 km	

Default values

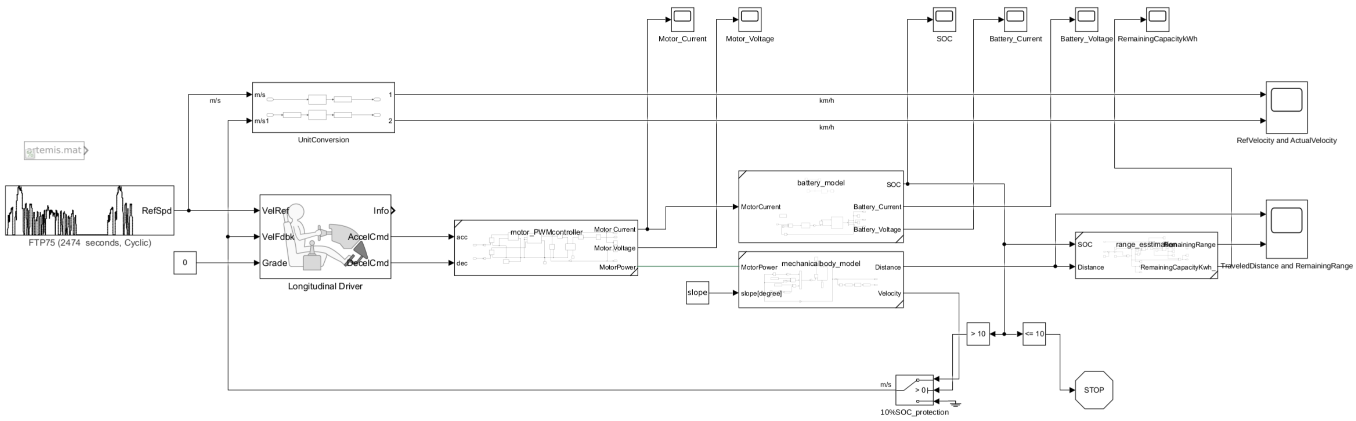
Variable	Value
aeroDragCoeff	0.18

Variable	Value
rollingResistCoeff	0.008
frontArea	3 m2
regen_efficency	1
motor_gear_ratio	7
towing_ratio = 1	1
massCaravan	250 kg
massStorage	200 kg
nTires	2
massTire	20 kg
radiusTire	0.3 m
rated_speed	25000 rpm
rated_load	250 kWh
battery_low_cut_off	5%
battery_high_cut_off	95%
NominalVoltage	370 V
Capacity_Ah	350 Ah
battEnergyDensity	240 Wh/kg
slope	0 rad

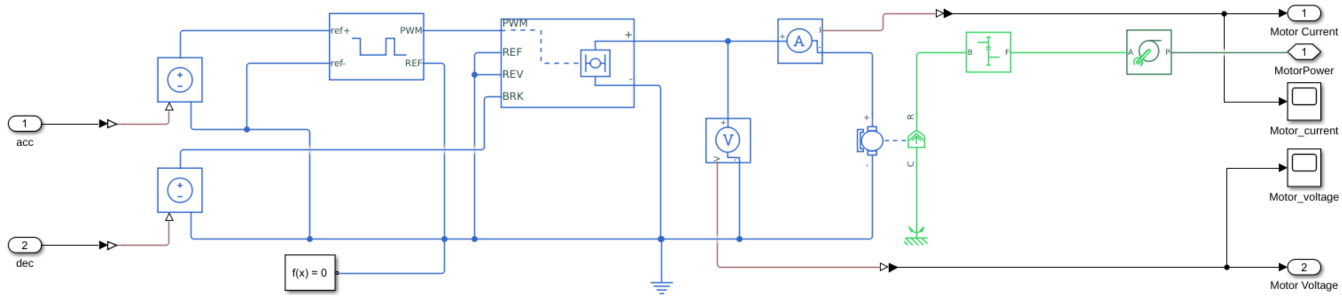
With the default parameters the SPC gives a 365 km range and an efficiency of 3.1 km/kWh. Both the range and the efficiency are influenced in the same way so only the offect of the variable on the range will be investigated

Images

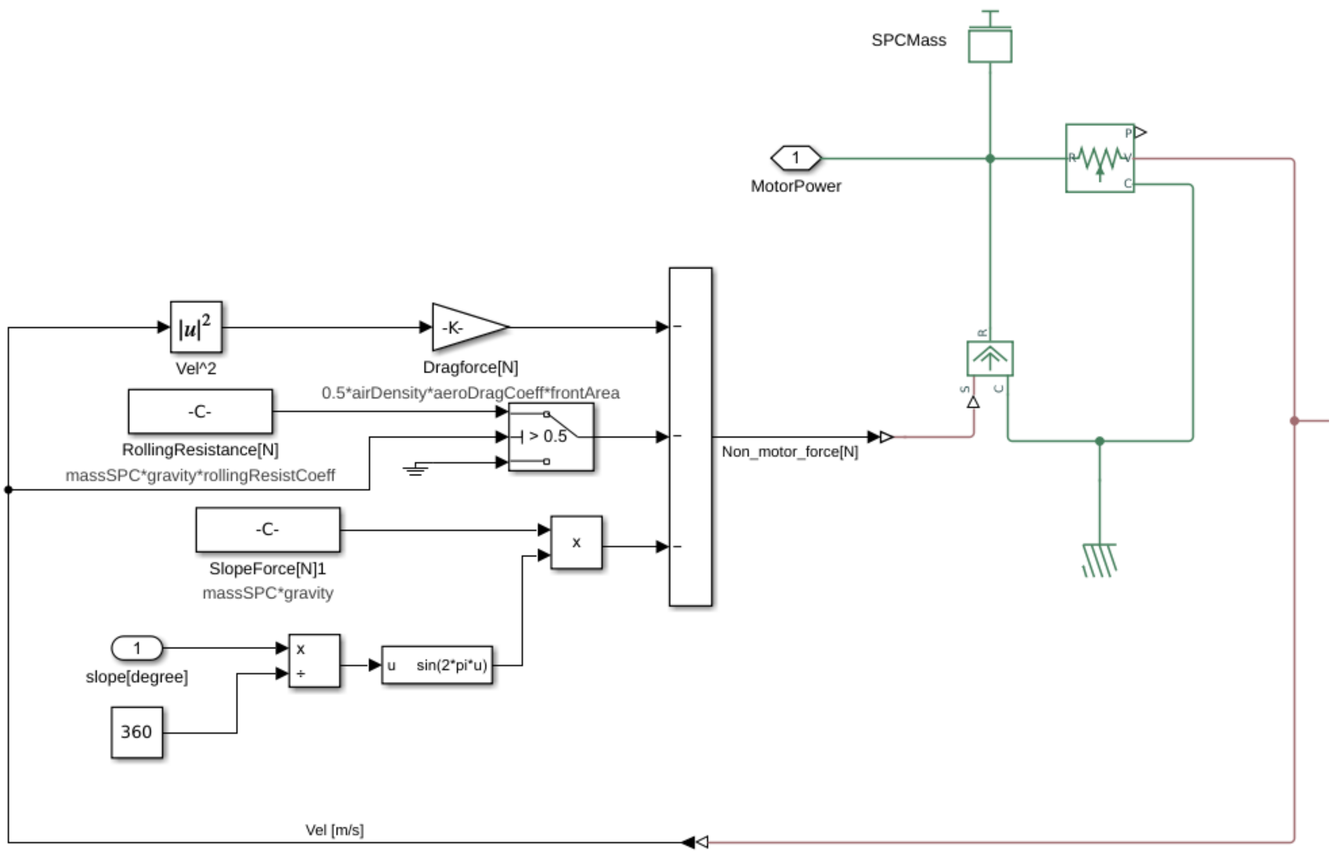
Main model



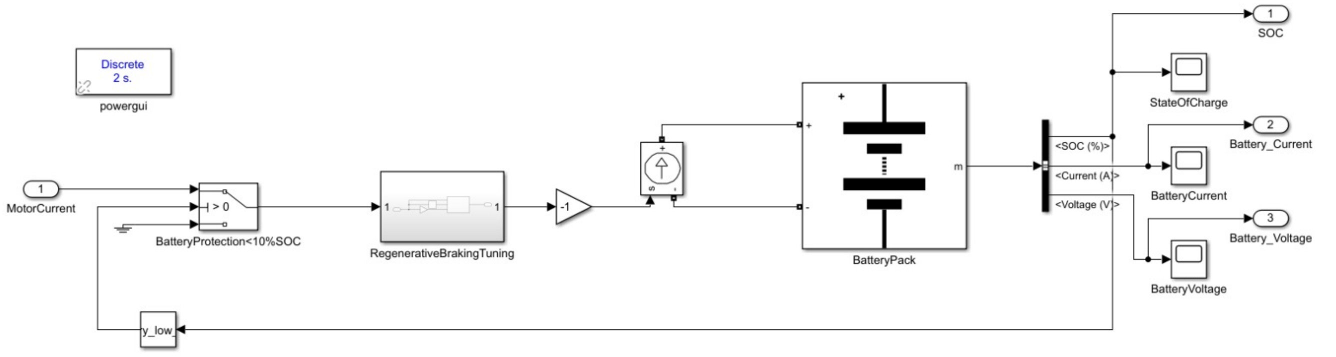
Motor PWM Controller



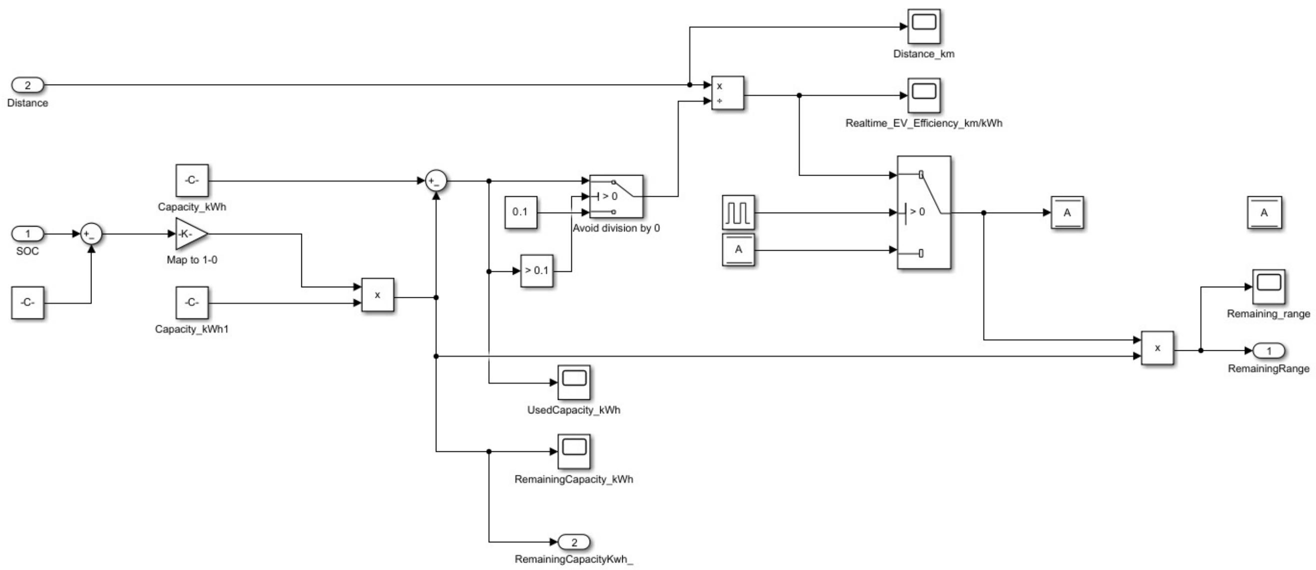
Mechanical model (Point mass)



Battery model



Range estimation and efficiency calculation



Future Work

- Include a model of the pulling car
  - maybe a presets of popular EVs, such as a tesla model 3 or an Audi E-tron
- Simulate the airodynamics of pulling a caravan
  - is is quite important since air drag is the most imporant aspect towards efficiency.
  - Requires CFD
- Battery charge ballancing between the caravan and the pulling car.
- 3D-model with turning forces
- SlopeCycle - including multiple altitudes along a route