Model Predictive Control with handling of Unreachable Set-points in Diesel Engines

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Background

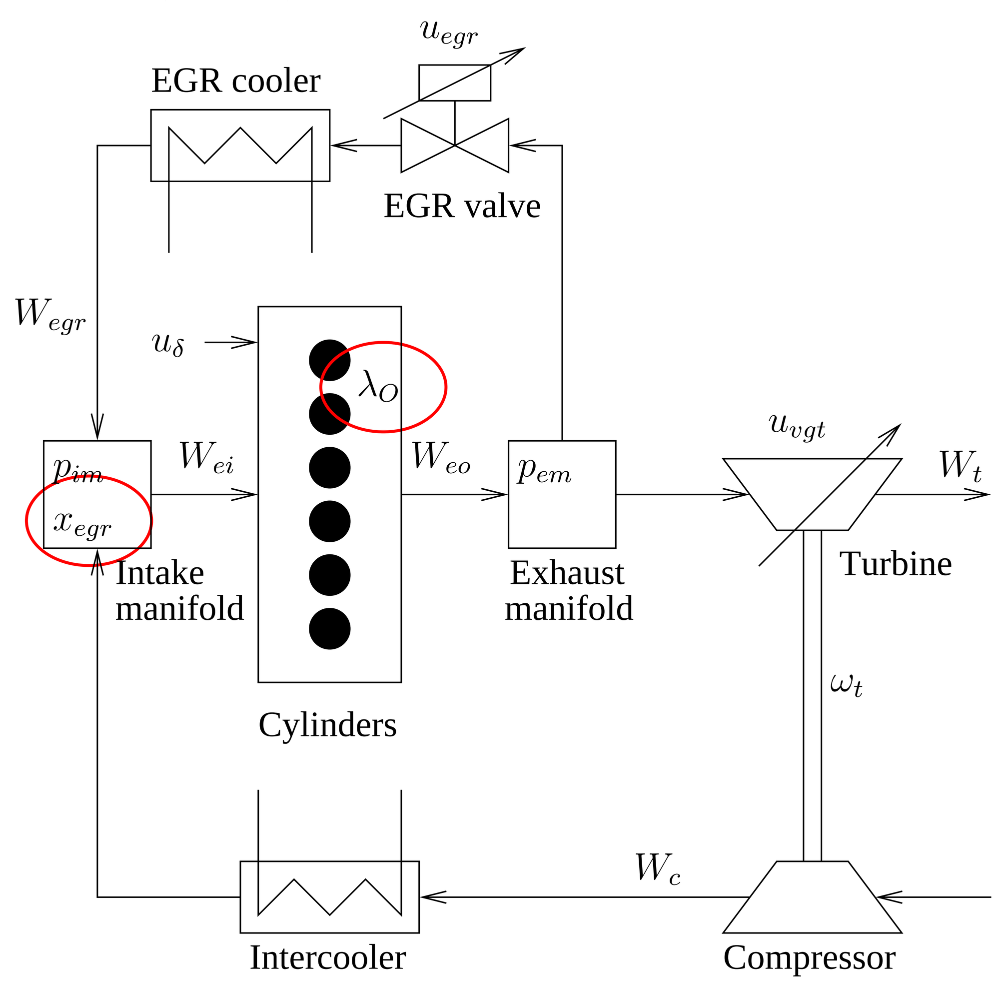
Overall goal:

- Fulfill legislated emission limits (smoke and NO_x)
- Optimize fuel consumption (pumping work)
- This requires: coordinated control of Exhaust Gas Recirculation (EGR) and Variable Geometry Turbine (VGT)

Main performance variables:

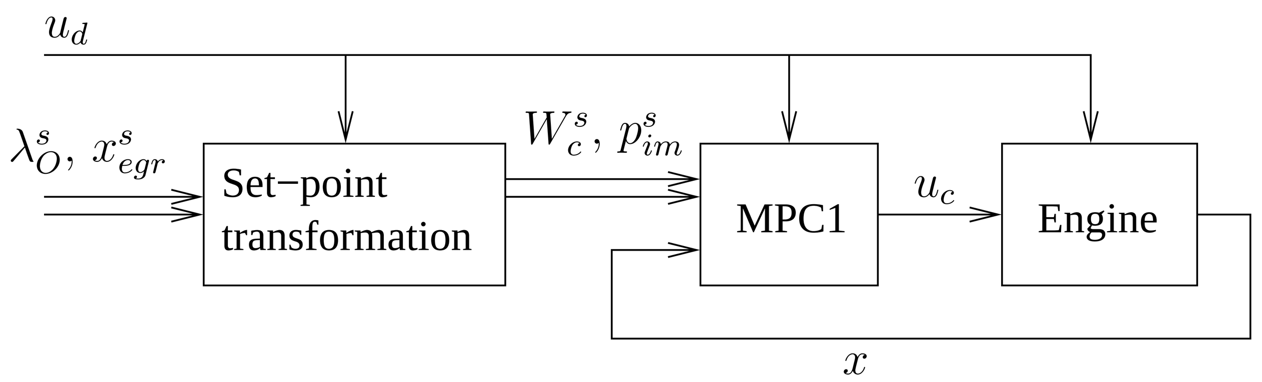
- Oxygen-fuel ratio λ_O
- EGR-fraction x_{egr}

Motive: Strongly connected to emissions



Controller 1

A model predictive control design is proposed in Ferreau (2007)



- Outputs in the cost-function: compressor mass flow W_c and intake manifold pressure p_{im}
- Motive: These outputs are measurable and all the states x needed by the MPC are measurable
- MPC problem (MPC1)

$$\min \sum_{j=N_1}^{N_2} q_1(W_c(j) - W_c^s)^2 + q_2(p_{im}(j) - p_{im}^s)^2 + \sum_{j=0}^{N_c} ||\Delta u_c(j)||^2_{Q_3}$$

$$\text{s.t. } u_{c,min} \le u_c(j) \le u_{c,max}$$

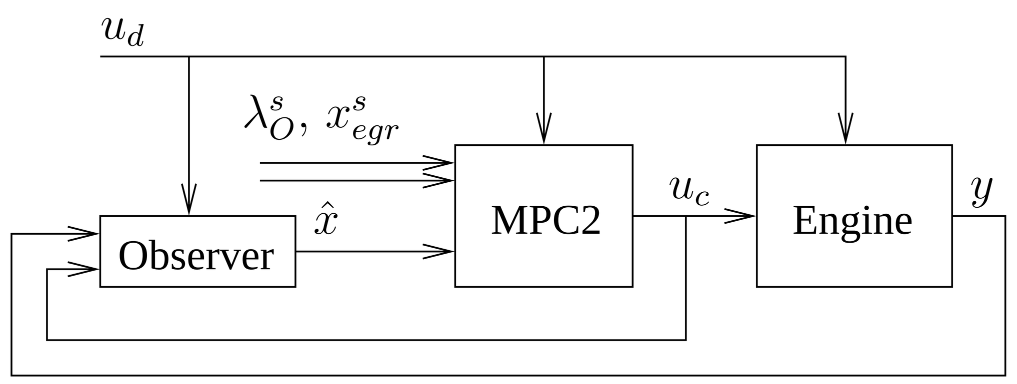
- Control inputs u_c: EGR and VGT position
- Measurable disturbances u_d: Engine speed and fuel injection

Problem:

- If $\lambda_O > \lambda_O^s$ (which is allowed in diesel engines) and λ_O^s is unreachable, W_c^s and/or p_{im}^s become unreachable $\Rightarrow$ tracking of x_{egr}^s cannot be guaranteed even if x_{egr}^s is reachable

Controller 2

Handles unreachable set-points using the following control structure



- Outputs in the cost function: EGR-fraction x_{egr} and pumping losses $p_{em} - p_{im}$
- Constraint: $\lambda_O > \lambda_O^s$
- MPC problem (MPC2)

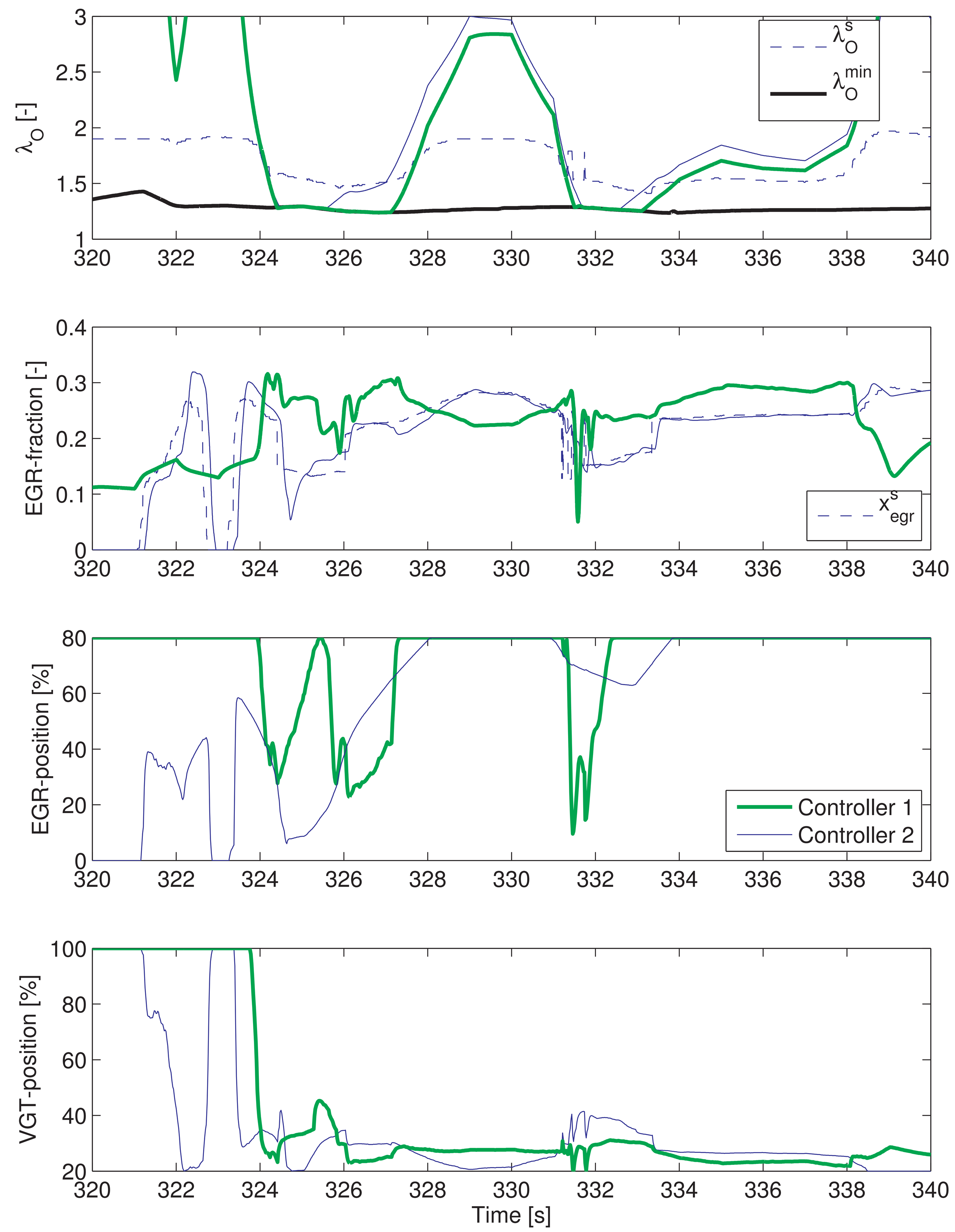
$$\min \sum_{j=N_1}^{N_2} q_1(x_{egr}(j) - x_{egr}^s)^2 + q_2(p_{em}(j) - p_{im}(j)) + \rho\epsilon(j) + \sum_{j=0}^{N_c} ||\Delta u_c(j)||^2_{Q_3}$$

$$\text{s.t. } u_{c,min} \le u_c(j) \le u_{c,max}, \quad \lambda_O(j) + \epsilon(j) \ge \lambda_O^s, \quad \epsilon(j) \ge 0$$

- Controller 2 requires more states x that are not measurable $\Rightarrow$ an observer is used

Simulations for an aggressive ETC transient

Controller 1 gives a fully open EGR and VGT position at 320-324 s in order to decrease W_c and p_{im}. However, W_c^s and p_{im}^s are unreachable due to that $\lambda_O >> \lambda_O^s$. However, this is allowed in diesel engines and controller 2 handles this by controlling x_{egr} and $p_{em} - p_{im}$ instead leading to less EGR-error.



Simulations for the complete ETC

The following measures are compared

$$E_{\lambda_O} = \sum_{i=1}^{N} \max(\lambda_O^s(t_i) - \lambda_O(t_i), 0), \quad E_{x_{egr}} = \sum_{i=1}^{N} |x_{egr}^s(t_i) - x_{egr}(t_i)|$$

$$PMEP = \sum_{i=1}^{N} (p_{em}(t_i) - p_{im}(t_i))$$

Controller	E_{λ_O}	$E_{x_{egr}}$	$PMEP$
1	1.00	1.00	1.00
2	0.90	0.17	0.88

Controller 2 reduces λ_O-error, EGR-error, and pumping losses compared to controller 1