Institute for Design and Control of Mechatronical Systems

# Diploma Thesis:

# MPC for a Diesel Engine Airpath using an Explicit Approach for Constraint Systems


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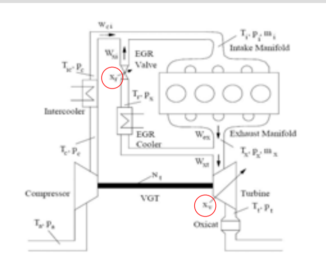
## Abstract

In this diploma thesis a recently developed controller design (explicit MPC) is used for the airpath control of a diesel engine. The explicit solution of linear quadratic regulator (LQR) with constraints offers the opportunity of calculating the explicit solution of the state feedback control law offline and storing it in tables for online controller selection (Look Up Tables). So the computational expense can be shifted from online to offline calculation which is essential for high speed applications like engine control. The combination of plant and switched controller leads to a piecewise linear and discrete system – a special form of hybrid system.


## The EGR – VGT Control Problem




**EGR → MAF:** opening the EGR valve → EGR flow is increasing → MAF is decreasing

**VGT → MAP:** closing the guide vanes → exhaust gas flow is more restricted → turbocharger speed increases → MAP increases

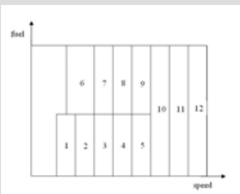
**EGR → MAP:** open the valve → less exhaust gas enters the turbine → slowing down turbocharger speed → decreasing MAP

**VGT → MAF:** closing the guide vanes → exhaust gas flow is more restricted → increase in the exhaust manifold pressure → increased EGR flow → MAF reduces

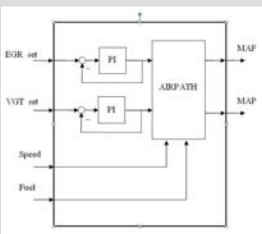
## Identification of the airpath model using PEM second order

### Divide operating area

Due to the fact that it isn't possible to cover the whole operating area (engine speed and injected fuel amount) of the Diesel engine with one linear model it is a very common approach to divide the operating area in smaller regions and identify one linear model on each region.

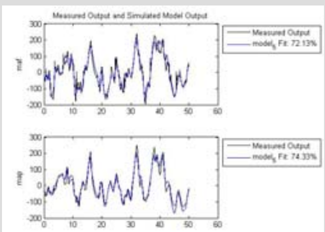



### Model structure



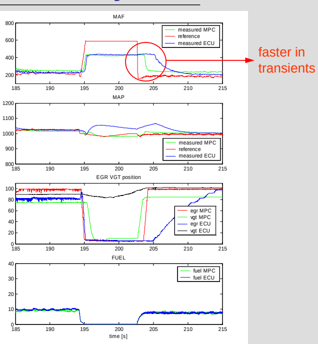

include engine speed and injected fuel amount as external inputs

### Identification result

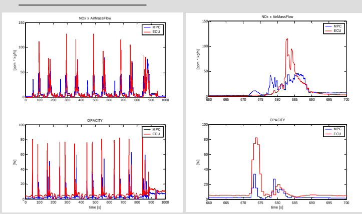



Model validation (area 5) using data, which wasn't used for identification

## ECE Cycle




## Emissions

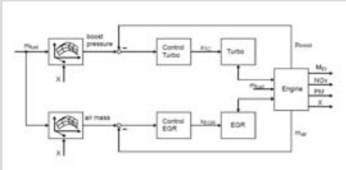


Simplified ECU:
NOx: 7,79 OPA: 8,03

Explicit MPC (orig setpoints):
NOx: 10,6 OPA: 4,51

Explicit MPC (reachable MAF setpoints):
NOx: 8,64 OPA: 4,02

## ECU airpath control (SISO)

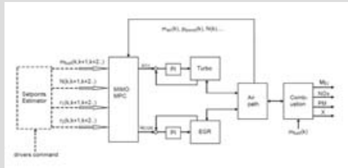



Two SISO control loops (PID):

MAF is controlled with EGR

MAP is controlled with VGT

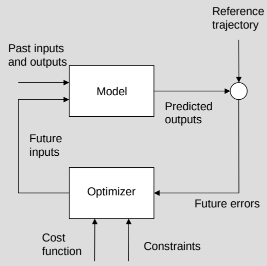
## MIMO airpath control

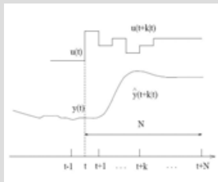


One MIMO controller + two low level position (PI) controller

Advantage: Consideration of the "cross coupling" *EGR → MAP* and *VGT → MAF*

## Model Predictive Control (MPC)



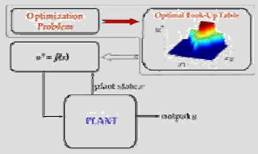
- The future outputs for a determined horizon are predicted at each instant using the process model. These predicted outputs depend on the known values up to instant and on the future control signals , which are those to be sent to the system.
- The set of future signals is calculated by optimizing a cost function to keep the process as close as possible to the reference trajectory. The cost function usually takes the form of a quadratic function of the errors between the predicted output signal and the reference trajectory.
- The control signal is sent to the process whilst the next control signals calculated are rejected.

## Explicit Formulation

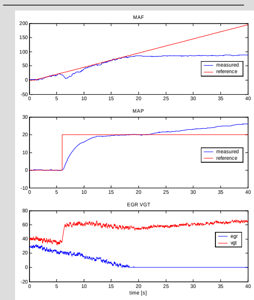
Cost function: $$\min_{U\triangleq\{\delta u_t,\dots,\delta u_{t+Nu-1}\}} \sum_{k=0}^{N_y-1}\left\{\left[y_{t+k|t}-r(t)\right]' Q \left[y_{t+k|t}-r(t)\right]+\delta u'_{t+k|t}\, R\, \delta u_{t+k|t}\right\}$$

Continuous and piecewise affine (PWA) solution

$$U^*\left(x(0)\right)=F_k\, x(0)+G_k$$
$$if\;\; x(0)\in P_k=\left\{x\in\mathbb{R}^n \mid H_k\, x\le K_k\right\},\; k=1,\dots,M$$

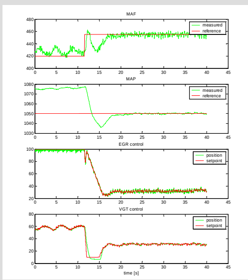



## Setpoint problem

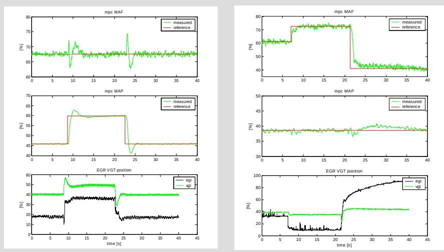


boost pressure is "track-able". From 18 sec on EGR is saturated and can no longer track MAF. Instead of continuing tracking MAP, VGT tries to minimize the MIMO cost function where both tracking errors are weighted equal.

**If one setpoint is chosen unreachable, tracking of the other reference even if it is reachable cannot be guaranteed.**



## Step references



## Conclusion

- Engine speed and injected fuel amount are essential variables for airpath modeling
- PEM is the best choice for identification of airpath models
- Be careful with constraints (polyhedral partition)
- As results show MAF and MAP can be tracked better than with the standard 2 SISO controllers of the ECU.
- In the ECE cycle the opacity could be reduced by 50% meanwhile increasing NOx only by 10%.
- It is essential to use reachable setpoints in a MIMO control

## Outlook

- Usage of optimized search algorithm for the controller selection
- Including future references & measured disturbances
- Online MPC solution
- Reachable MAP setpoints
- Method for limitation of the setpoints