Optimizacija parametara modelskog prediktivnog upravljanja pomoću genetskog algoritma

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1. **Model Predictive Control**
   - Parametri algoritma i princip rada
2. **Genetski algoritmi**
   - Parametri algoritma i princip rada
3. **Primjena genetskog algoritma na MPC**
   - Objekt upravljanja
   - Formiranje fitness funkcije
     - Analiza parametara odziva pneumatskog aktuatora
     - Formiranje dataseta i interpolacija
     - Dodatne modifikacije
   - Optimiziranje MPC parametara
   - Rezultati

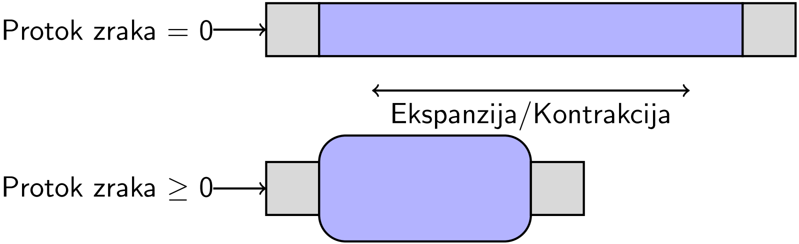

Figure: Princip rada pneumatskog aktuatora

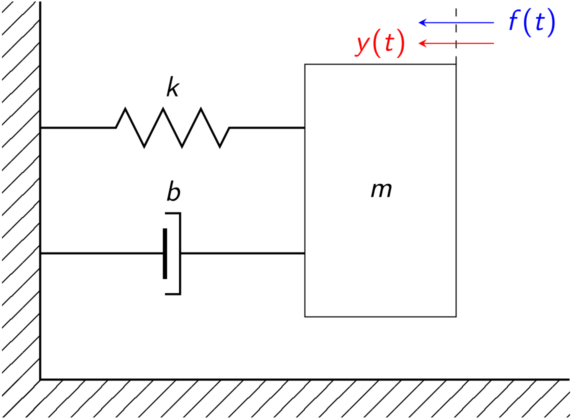

Figure: Shema sustava masa-opruga-prigušnica

$$f(t) - m\ddot{y}(t) - b\dot{y}(t) - ky(t) = 0, \tag{1}$$

$$x(t) = \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} = \begin{bmatrix} y(t) \\ \dot{y}(t) \end{bmatrix} \tag{2}$$

$$\dot{x}_1(t) = x_2(t) \tag{3}$$

$$\dot{x}_2(t) = \frac{1}{m} f(t) - \frac{b}{m} x_2(t) - \frac{k}{m} x_1(t) \tag{4}$$

$$\dot{q}(t) = -\frac{1}{\tau} q(t) + \frac{K}{\tau} u(t) \tag{5}$$

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{q}(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ -\frac{k}{m} & -\frac{b}{m} & \frac{\gamma A}{m} \\ 0 & 0 & -\frac{1}{\tau} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ q(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{K}{\tau} \end{bmatrix} u(t)$$

- argumenti $\longrightarrow$ p, Q_{11}
- cilj $\longrightarrow$ optimalni omjer
- funkcija $\longrightarrow$ $f(p, Q_{11})$
- formiranje trodimenzionalnog prikaza *fitness* funkcije i pronalazak minimuma

Primjena genetskog algoritma na MPC

Analiza parametara odziva pneumatskog aktuatora

- greška u stacionarnom stanju ε, vrijeme porasta t_r

odziv_MPC_lose-eps-converted-to.pdf

Implementation on a linear pneumatic muscle

Problems and issues

- 3 state variables
- steady-state error - unable to compare with LQR and assess the validity
- the error dependent on $\mathbf{Q}$ matrix and p
- approx. linear error ratio with respect to p changes
- nonlinear error ratio with respect to Q changes (unable to even measure)

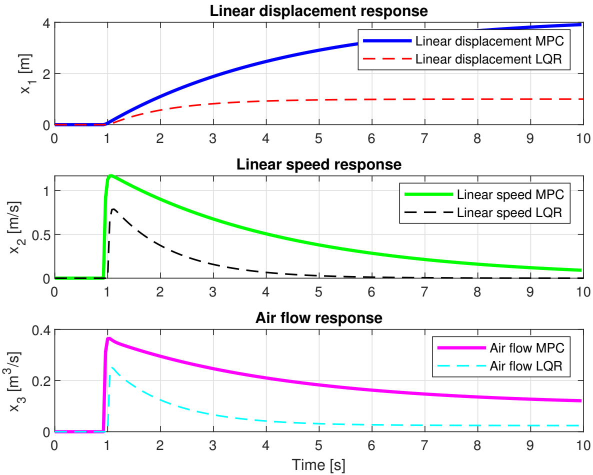

Figure: $Q_{LQR} = 1,\ Q_{MPC} = 1,\ p = 10,\ m = 3$

Implementation on a linear pneumatic muscle

Simulation results

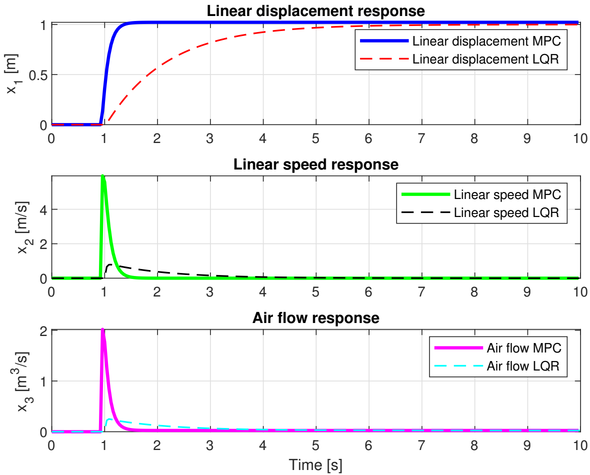

Figure: $Q_{LQR} = 1,\ Q_{MPC} = 100,\ p = 10,\ m = 3$

Implementation on a linear pneumatic muscle

Simulation results

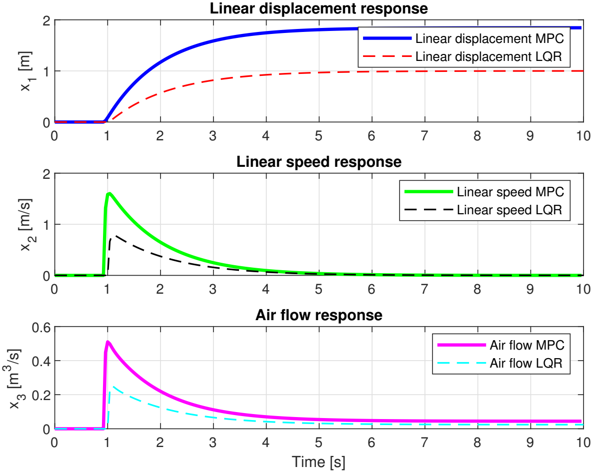

Figure: $Q_{LQR} = 1,\ Q_{MPC} = 1,\ p = 40,\ m = 3$

Implementation on a linear pneumatic muscle

Further analysis

- verify and adjust system parameters
- study interactions between changes in $\mathbf{Q}$, p, m, and T_s
- deep analysis of the code and MPC loop with regard to literature and papers

Implementation on a linear pneumatic muscle

Corrections

- continuous LQR $\longrightarrow$ discrete LQR
- elimination of the discretization error
- corrections were insignificant

```
Ksystem = dlqr(Ad, Bd, Q, R);        %dlqr instead of lqr
```

Model predictive control

Corrections

- state-space model correction
- missing coupling term between the airflow state (x_3) and the force (f)
- the force depends on the air pressure, affected by the airflow
- f **shouldn't be treated as an independent input**

$$\dot{x}_2(t) = \frac{1}{m} f(t) - \frac{b}{m} x_2(t) - \frac{k}{m} x_1(t) \tag{6}$$

$$\dot{x}_2(t) = \frac{\gamma A}{m} x_3(t) - \frac{b}{m} x_2(t) - \frac{k}{m} x_1(t) \tag{7}$$

- γ is a proportionality constant of the muscle, linking the airflow with the air pressure ($P = \gamma x_3$)
- A is effective cross-sectional area of the muscle

Model predictive control

Corrections

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{q}(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ -\frac{k}{m} & -\frac{b}{m} & {\color{red}0} \\ 0 & 0 & -\frac{1}{\tau} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ q(t) \end{bmatrix} + \begin{bmatrix} 0 \\ {\color{red}\frac{1}{m}} \\ \frac{K}{\tau} \end{bmatrix} \begin{bmatrix} 0 \\ f(t) \\ u(t) \end{bmatrix}$$

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{q}(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ -\frac{k}{m} & -\frac{b}{m} & {\color{red}\frac{\gamma A}{m}} \\ 0 & 0 & -\frac{1}{\tau} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \\ q(t) \end{bmatrix} + \begin{bmatrix} 0 \\ {\color{red}0} \\ \frac{K}{\tau} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ u(t) \end{bmatrix}$$

- 1 input $\longrightarrow$ voltage applied to the valve
- insignificant corrections in responses

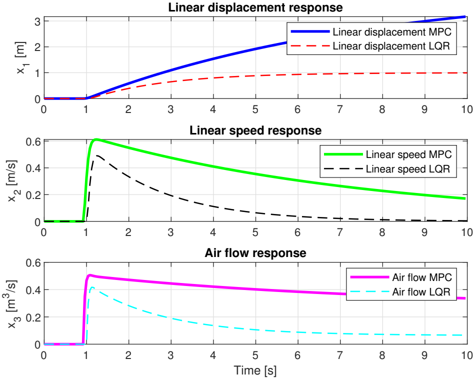

Figure: $Q_{LQR} = 1,\ Q_{MPC} = 1,\ p = 10,\ m = 3$

Model predictive control
Corrections

- **natural responses match at** $\approx p = 40$
- **forced responses mismatch**
- if we define the steady-state MPC error as

$$SS_{MPC} = e \cdot SS_{LQR} \tag{8}$$

and $SS_{LQR} = 0$, then SS_{MPC} must also be equal to 0

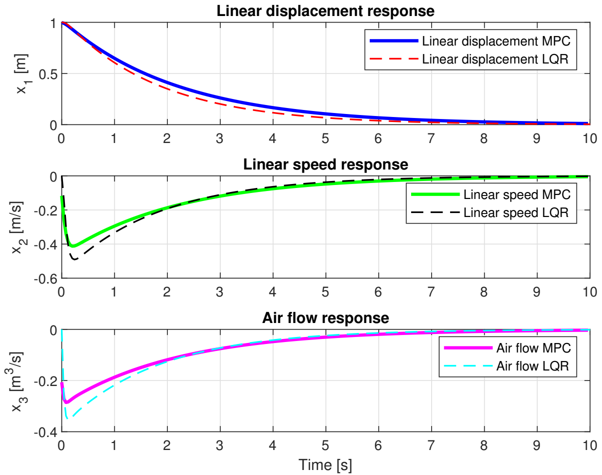

Figure: $Q_{LQR} = 1, \; Q_{MPC} = 1, \; p = 40, \; m = 3$

- valid constraints

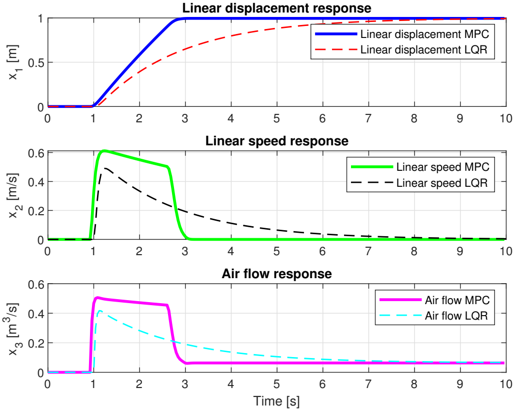

Figure: $Q_{LQR} = 1, \; Q_{MPC} = 1, \; p = 10, \; m = 3$

- MPC with $p \longrightarrow \infty$ approaches LQR

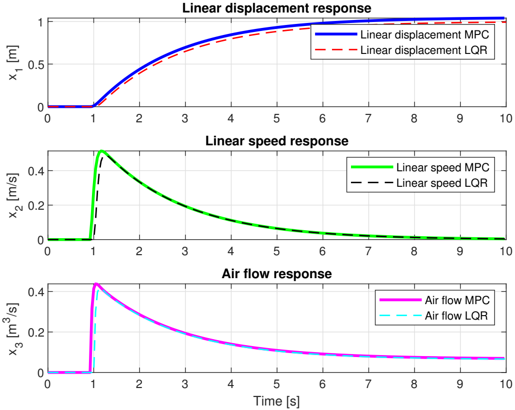

Figure: $Q_{LQR} = 1,\ Q_{MPC} = 1,\ p = 400,\ m = 400$

Thank you! Questions?