

Intelligent Robot Control

Lecture 5: Uporaba nelinearnih oscilatorjev v robotiki:
dvonivojski sistem

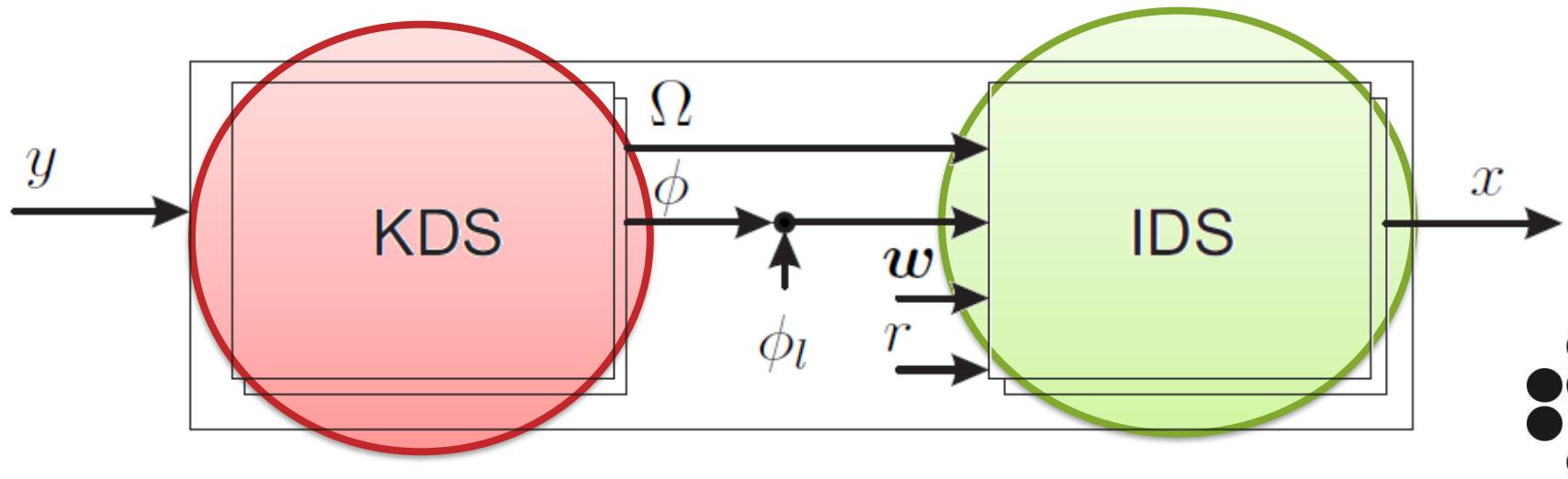
Tadej Petrič

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DVONIVOJSKI SISTEM

Izhodni dinamični sistem – IDS



Drugi nivo – Izhodni dinamični sistem

- Enostavno moduliranje
 - Frekvenčno
 - Amplitudno
- Učenje trajektorije brez da sistem izloči vse frekvenčne komponente signala
- Robustnost – diferencialne enačbe drugega reda

Izhodni dinamični sistem

$$\dot{z} = \Omega \left(\alpha_z (\beta_z (g - y) - z) + \frac{\sum_{i=1}^N \Psi_i w_i r}{\sum_{i=1}^N \Psi_i} \right),$$

$$\dot{y} = \Omega z$$

Jedrne funkcije

$$\Psi_i = \exp(h(\cos(\phi - c_i) - 1)),$$

Regresija

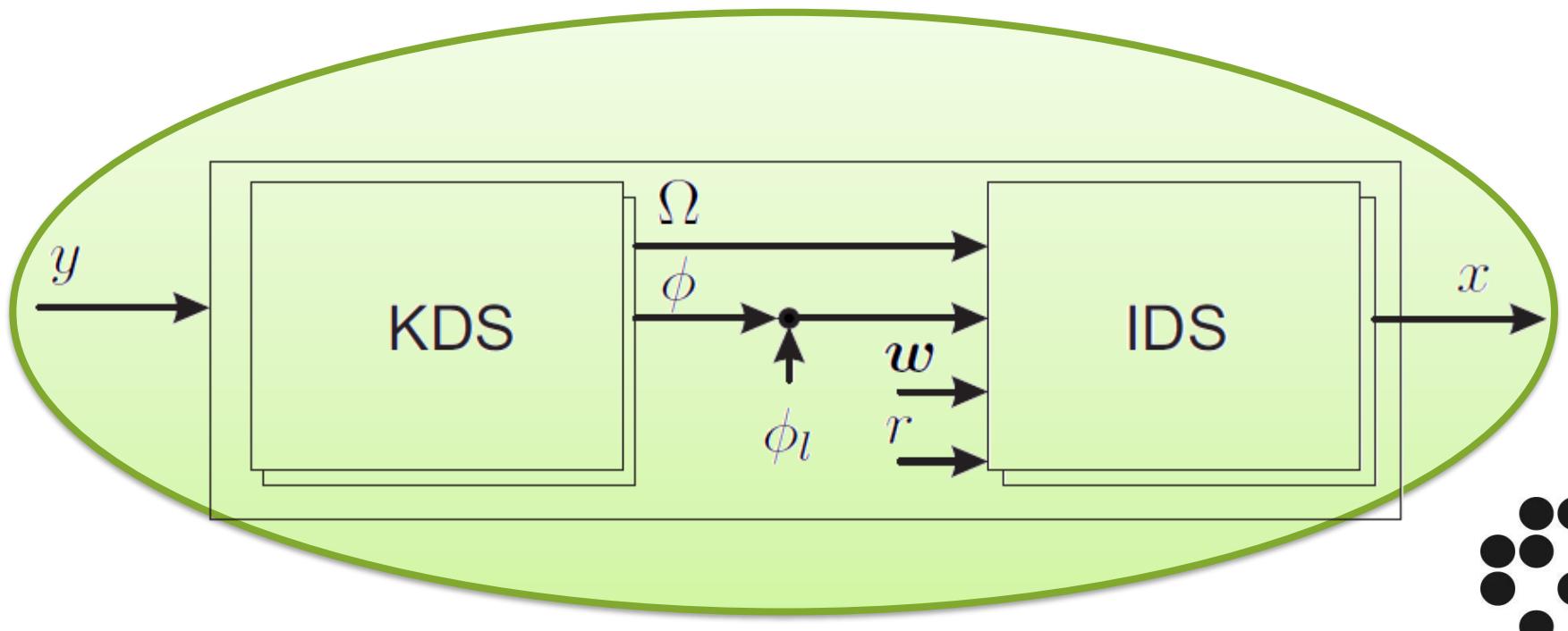
$$w_i^{t+1} = w_i^t + \Psi_i P_i^{t+1} r(t) e_r(t),$$

$$P_i^{t+1} = \frac{1}{\lambda} \left(P_i^t - \frac{P_i^{t2} r^{t2}}{\frac{\lambda}{\psi_i} + P_i^t r^{t2}} \right),$$

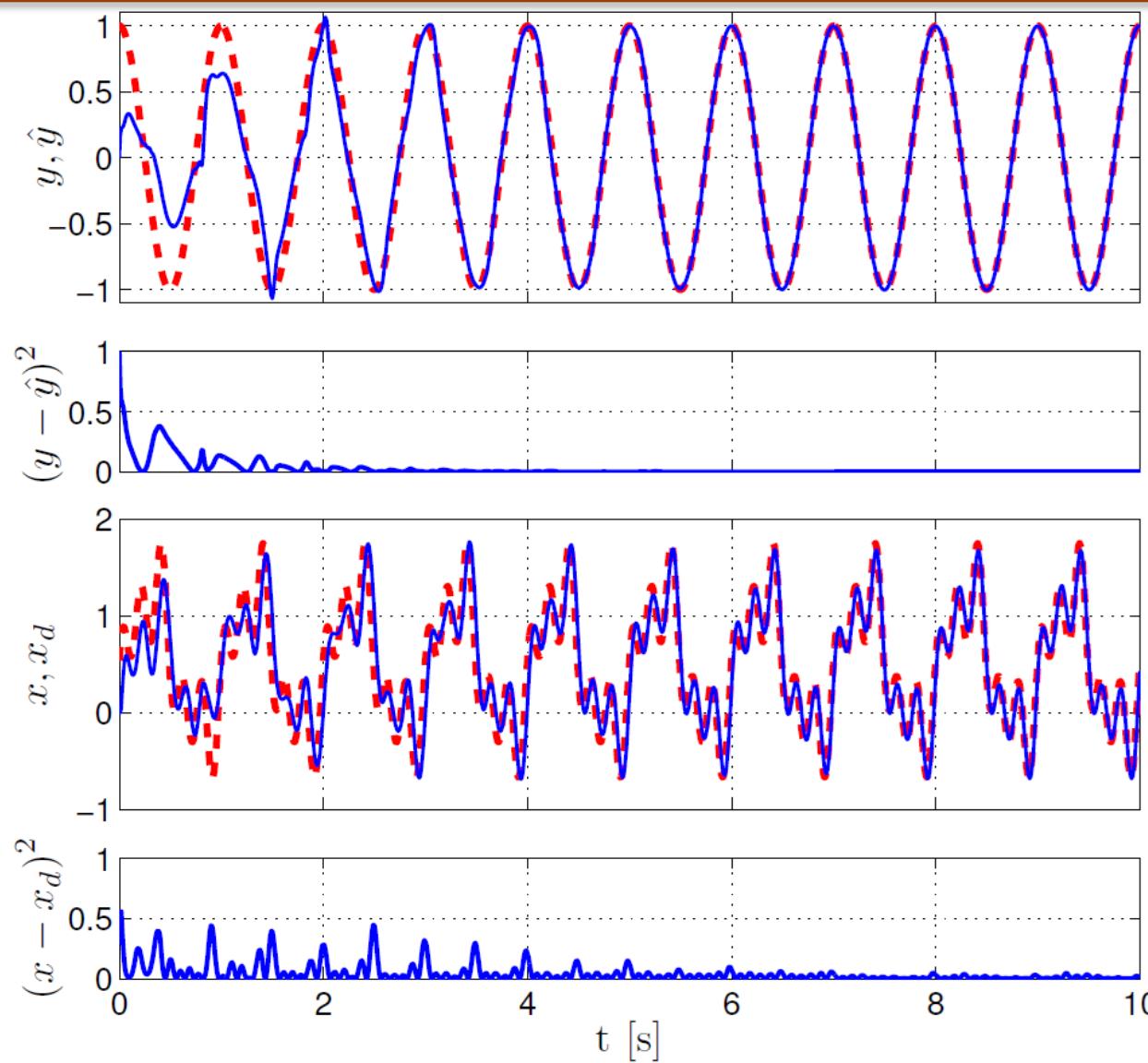
$$e_r(t) = f_{tar}(t) - w_i^t r(t),$$



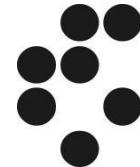
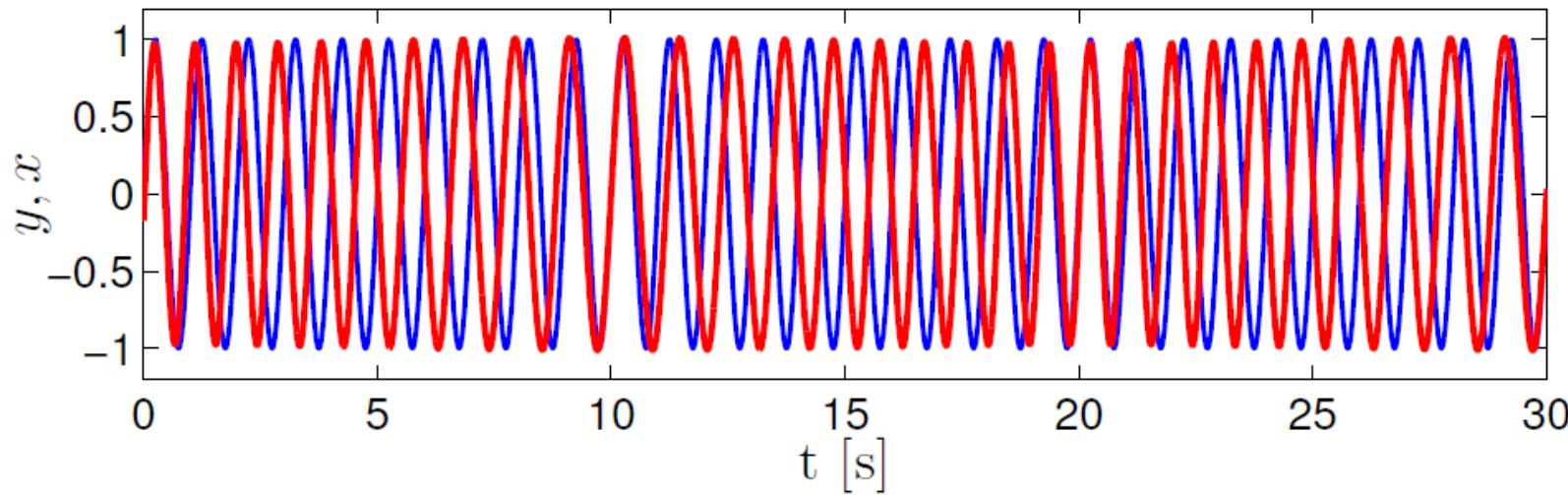
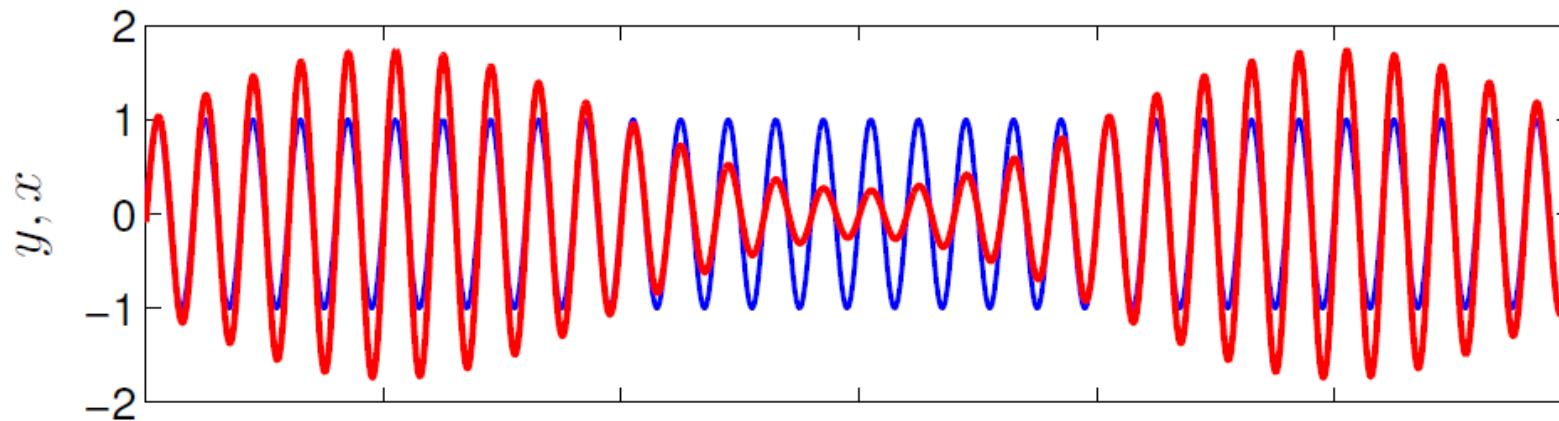
DVONIVOJSKI SISTEM



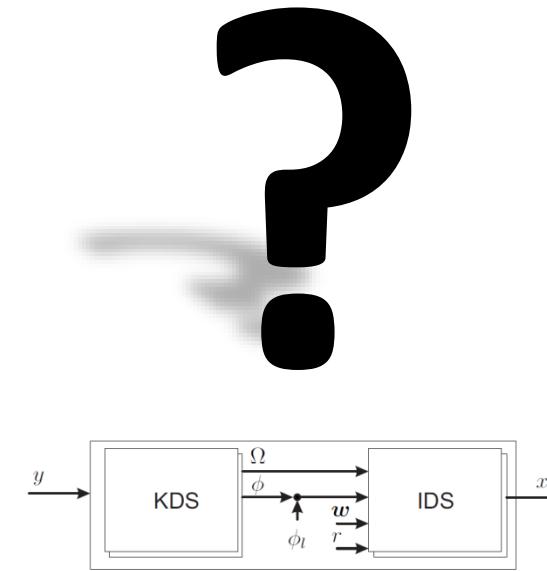
Hkratno učenje prvega in drugega nivoja



Amplitudna in fazna modulacija

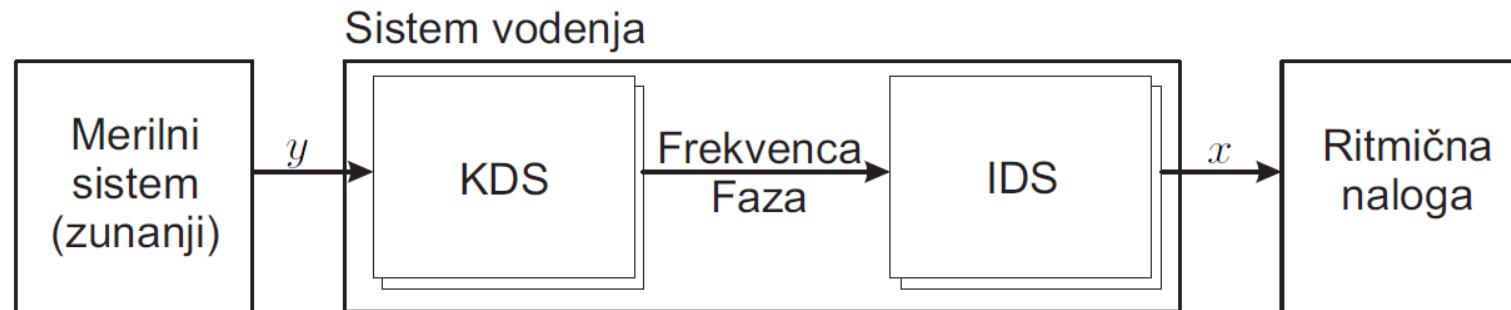


UPORABA DVO-NIVOJSKEGA SISTEMA ZA VODENJE ROBOTOV



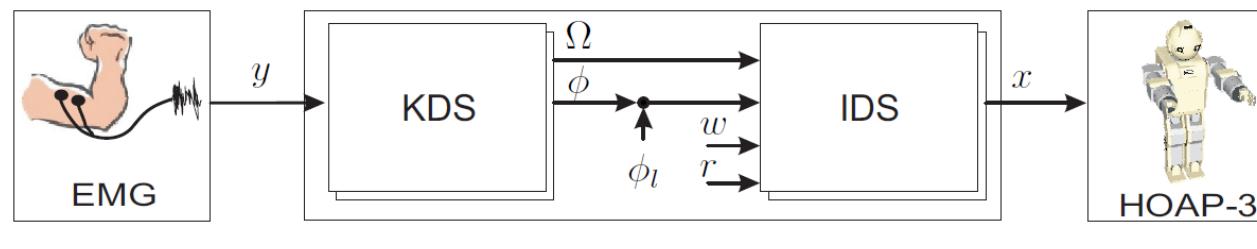
Vodenje ritmičnih nalog

- Sinhronizacija robota na zunanji merjeni signal (okolica), ki je relevanten za opravljanje določene ritmične naloge
 - Sinhronizacija robota na gibanje človeka
 - Bobnanje

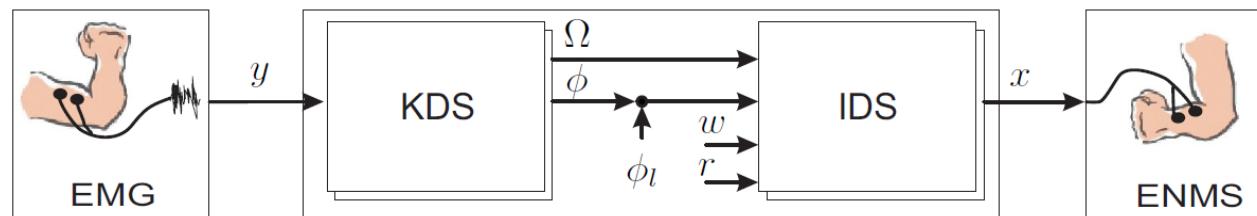


Sinhronizacija gibanja človeka in robota

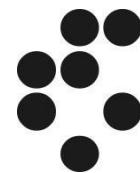
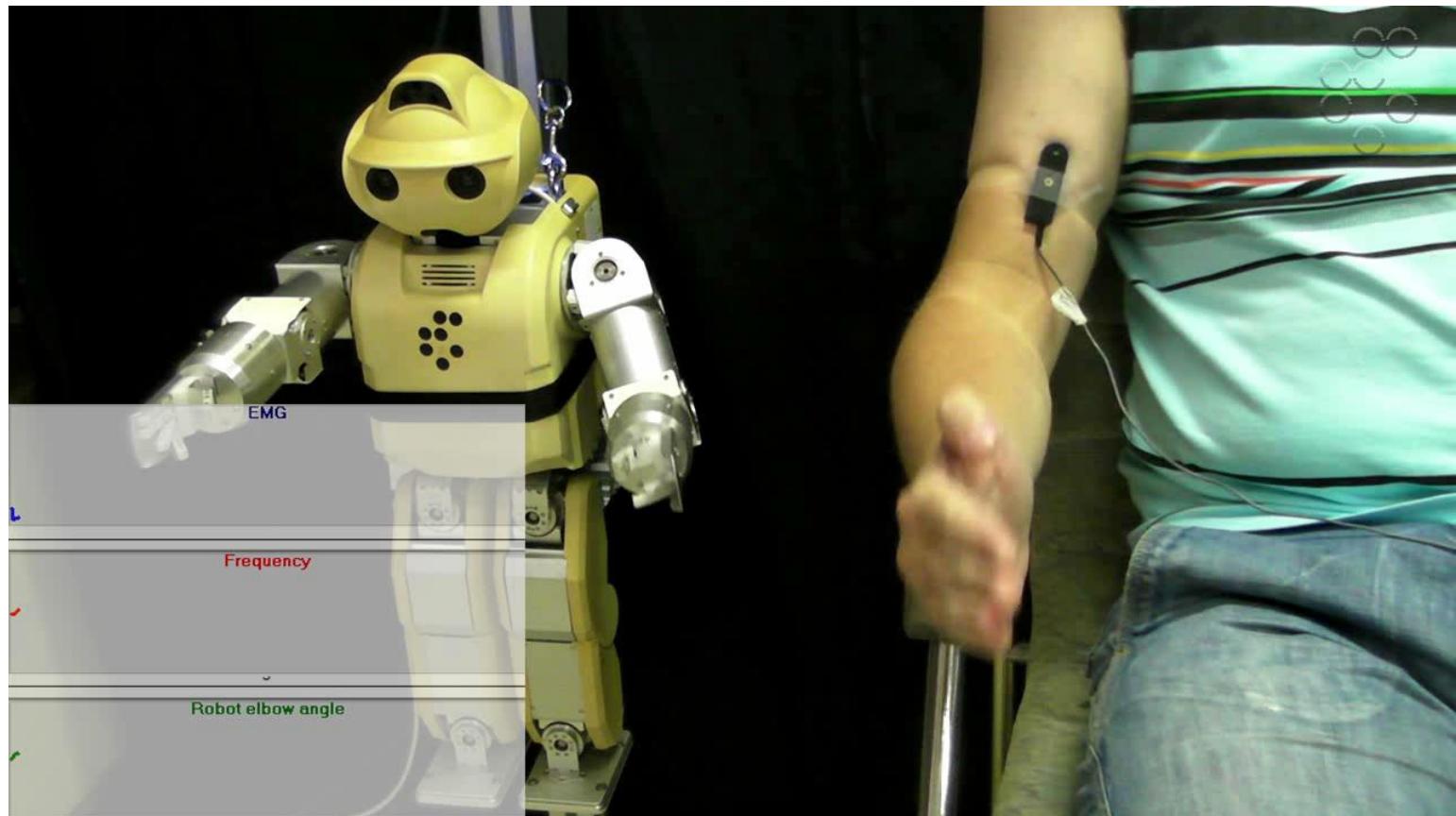
- Vhod v dvonivojski sistem je EMG signal
- Naloga zahtevna za izvedbo (šumen signal)



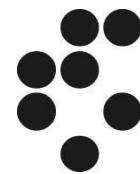
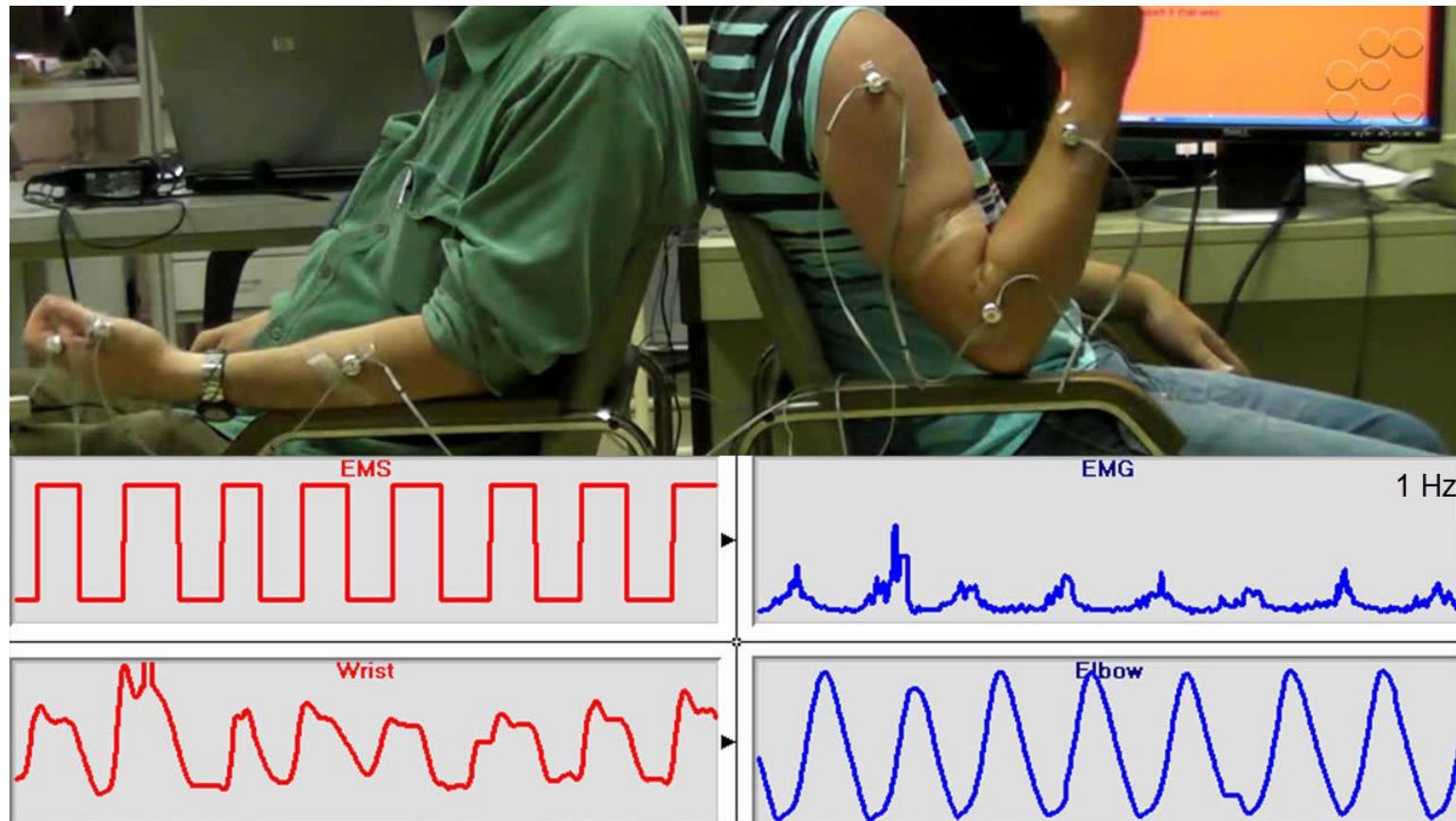
ALI



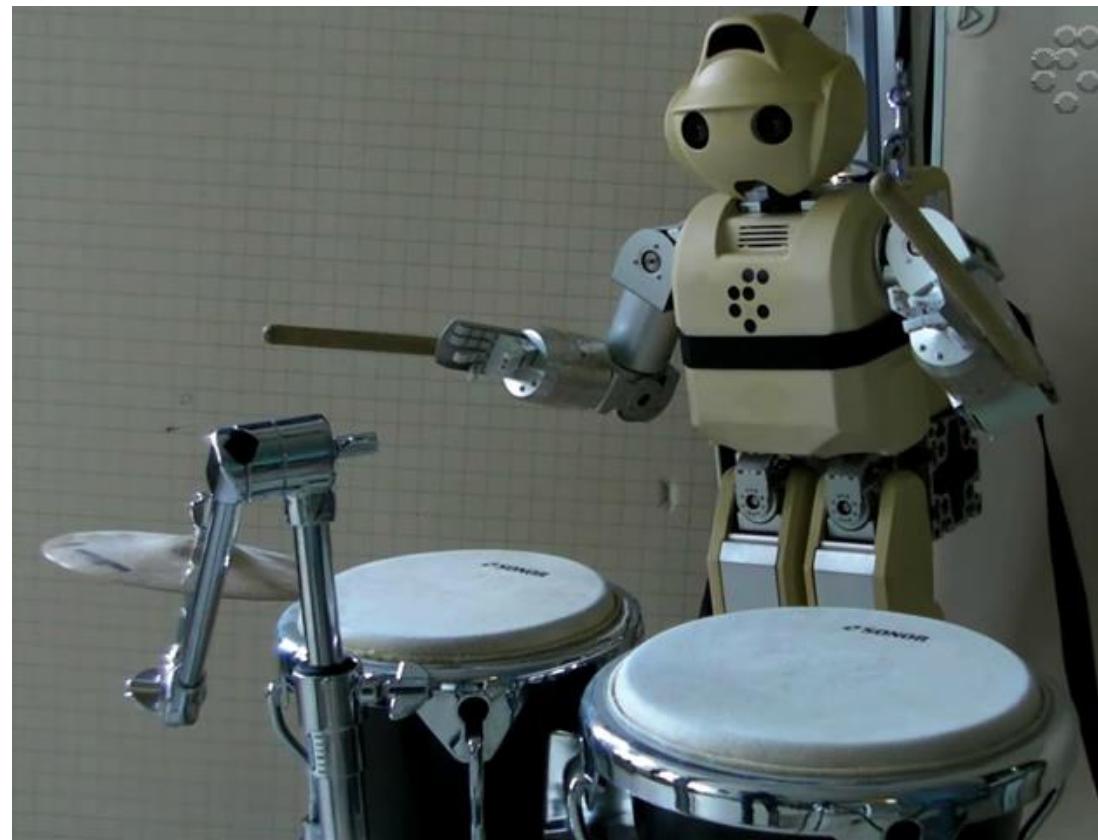
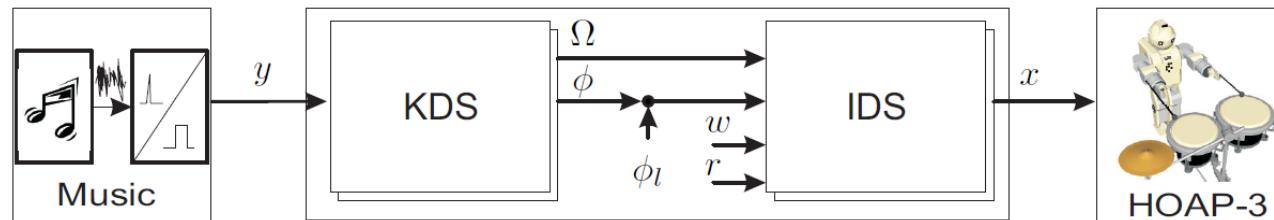
Video



Video

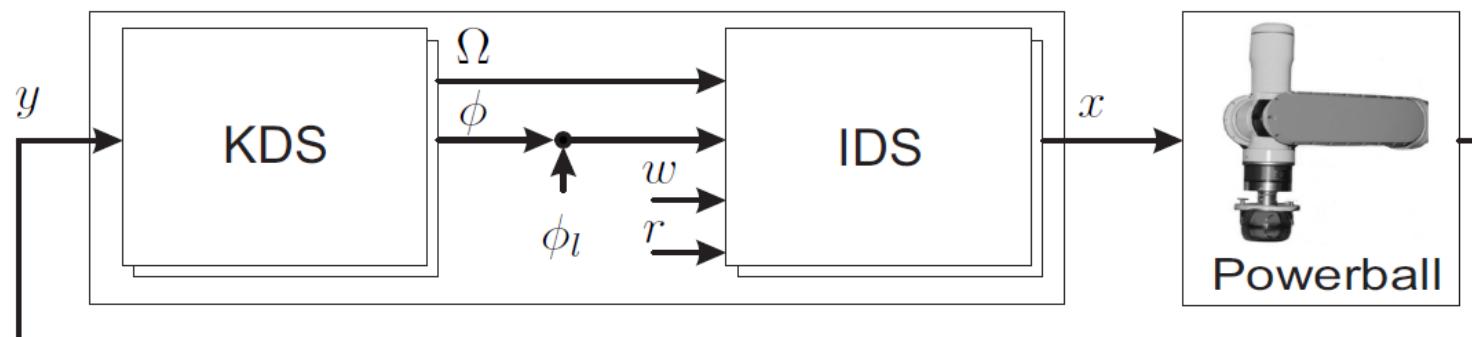


Robotsko bobnanje



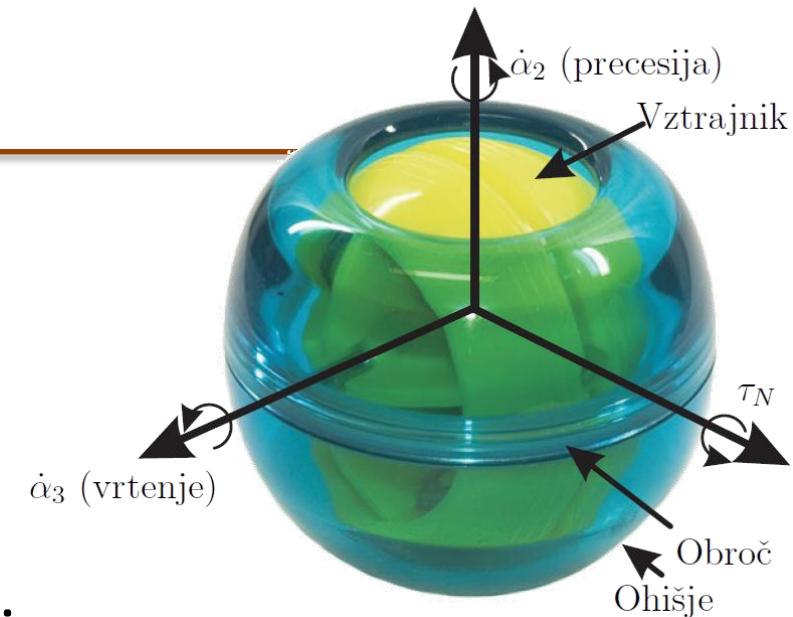
Sinhronizacija robota in vodene naprave: Robotiziran Powerball

- Sinhronizacija robota z nalogo, ki ima vsaj en merjen periodičen signal, kjer naloga neposredno vpliva na stanje sistema vodenja in obratno.
- Primer: igranje z napravo Powerball

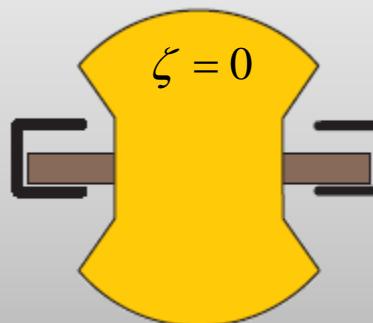


Powerball

- Rotor ima tri rotacijske prostostne stopnje
- Rotor potrebuje začetno vrtenje
- Translacija ne vplivajo na stanje rotorja

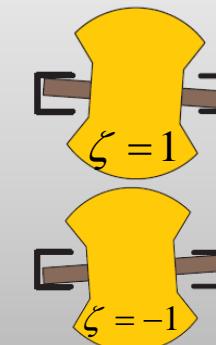


Normalno stanje:



$$\dot{\alpha}_3 \neq \left| \frac{\dot{\alpha}_4}{p} \right|$$

Stanje kotaljenja:



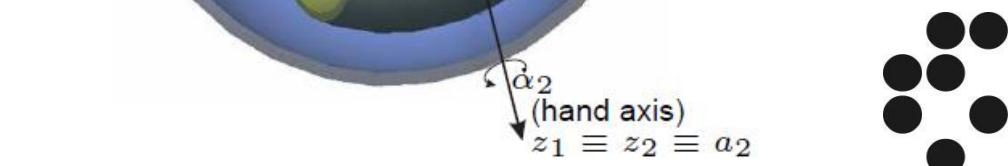
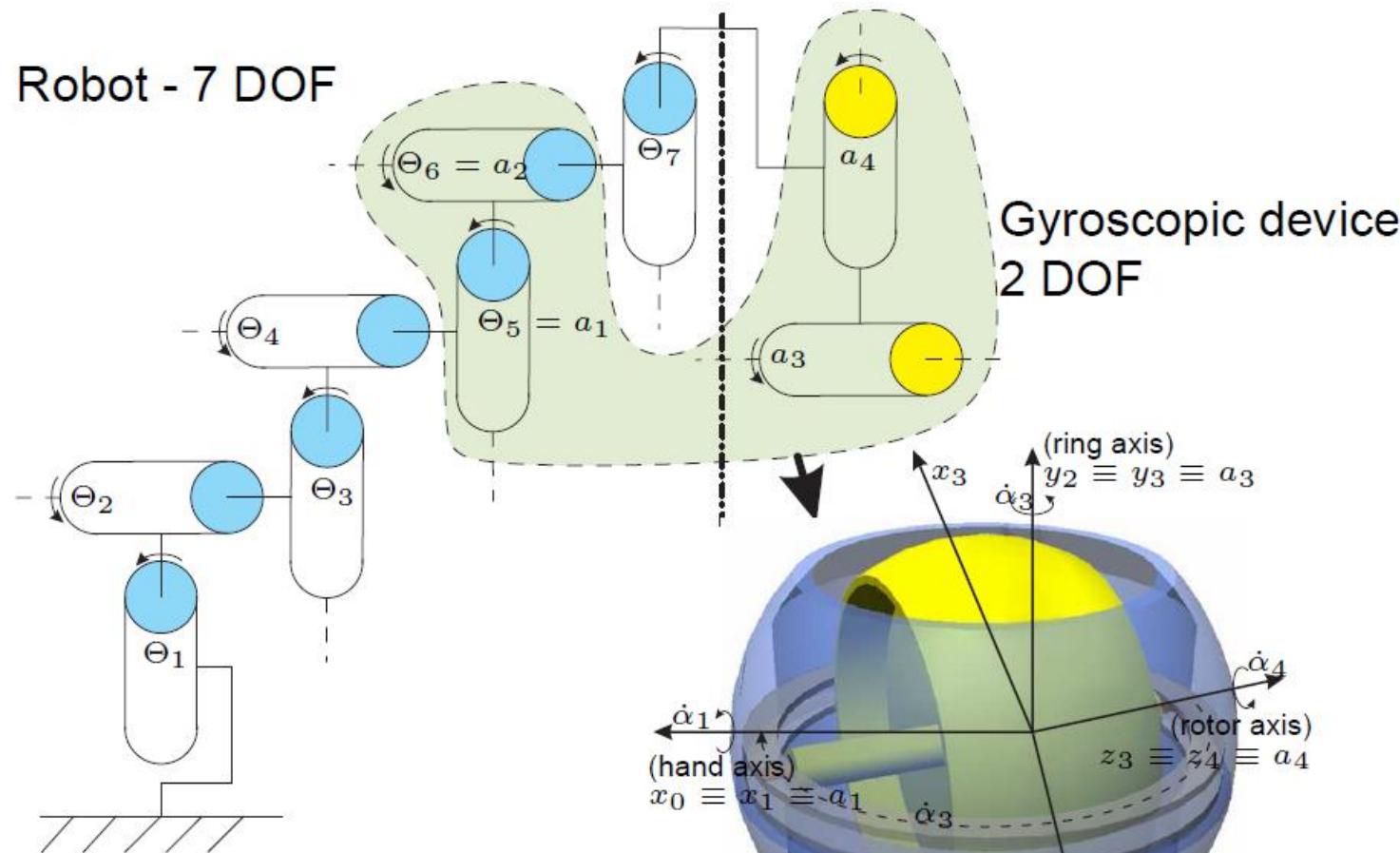
$$\dot{\alpha}_3 = \begin{cases} \frac{\dot{\alpha}_4}{p}, & \zeta = 1 \\ -\frac{\dot{\alpha}_4}{p}, & \zeta = -1 \end{cases}$$

$$p = \frac{r_3}{r_4} = 32$$



Kinematicna struktura

Robot - 7 DOF



Dinamični model

- Navor:

$$\begin{bmatrix} \tau_1 \\ \tau_2 \\ 0 \\ 0 \end{bmatrix} = H_{\underline{q}} \cdot \ddot{\underline{q}} + h_{\underline{q}}(\alpha, \dot{\alpha}) + \begin{bmatrix} \tau_{1f} \\ \tau_{2f} \\ \tau_{3f} \\ \tau_{4f} \end{bmatrix}$$

- Trenje:

$$\begin{bmatrix} \tau_{1f} \\ \tau_{2f} \\ \tau_{3f} \\ \tau_{4f} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \tau_{3z} + \tau_{3T} \\ \tau_{4z} + \tau_{4T} \end{bmatrix}$$

$$\tau_{3z} = k_v \cdot \dot{\alpha}_3$$

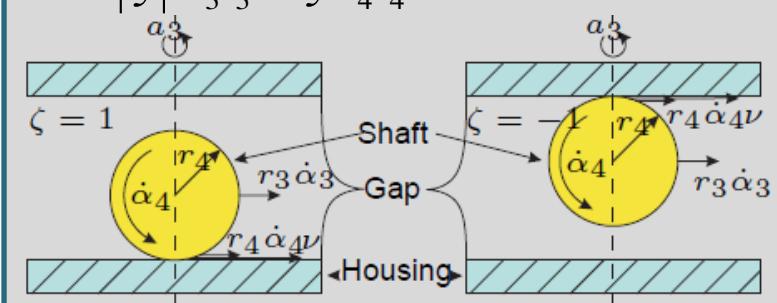
$$\tau_{3z} = \begin{cases} k_{v3} \dot{\alpha}_3 + k_{s3} \cdot \text{sign}(\dot{\alpha}_3); \zeta = 0, \\ 0; \zeta \neq 0 \end{cases}$$

$$\tau_{3T} = -\zeta \cdot \frac{1}{p} \cdot f_t(v, \tau_N)$$

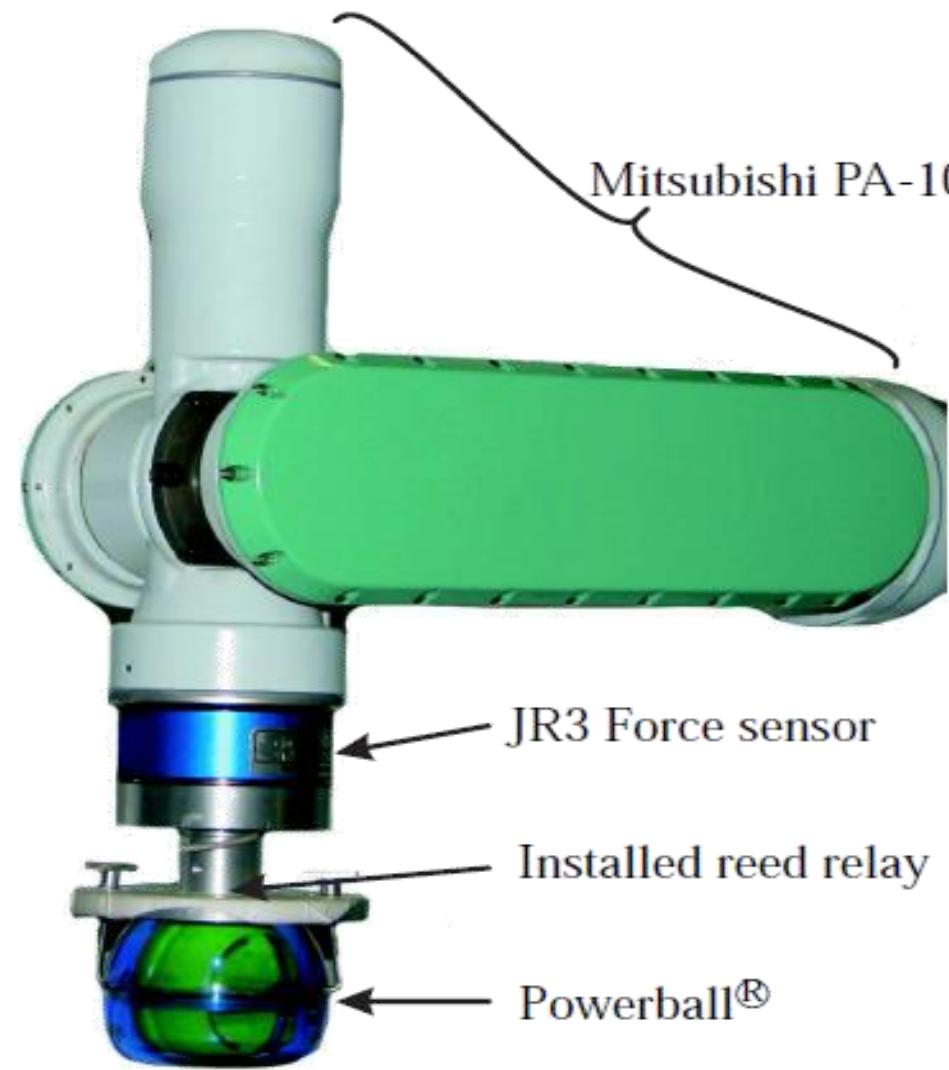
$$\tau_{4T} = -f_t(v, \tau_N)$$

$$f_t(v, \tau_N) = k_s \text{sig}(v)$$

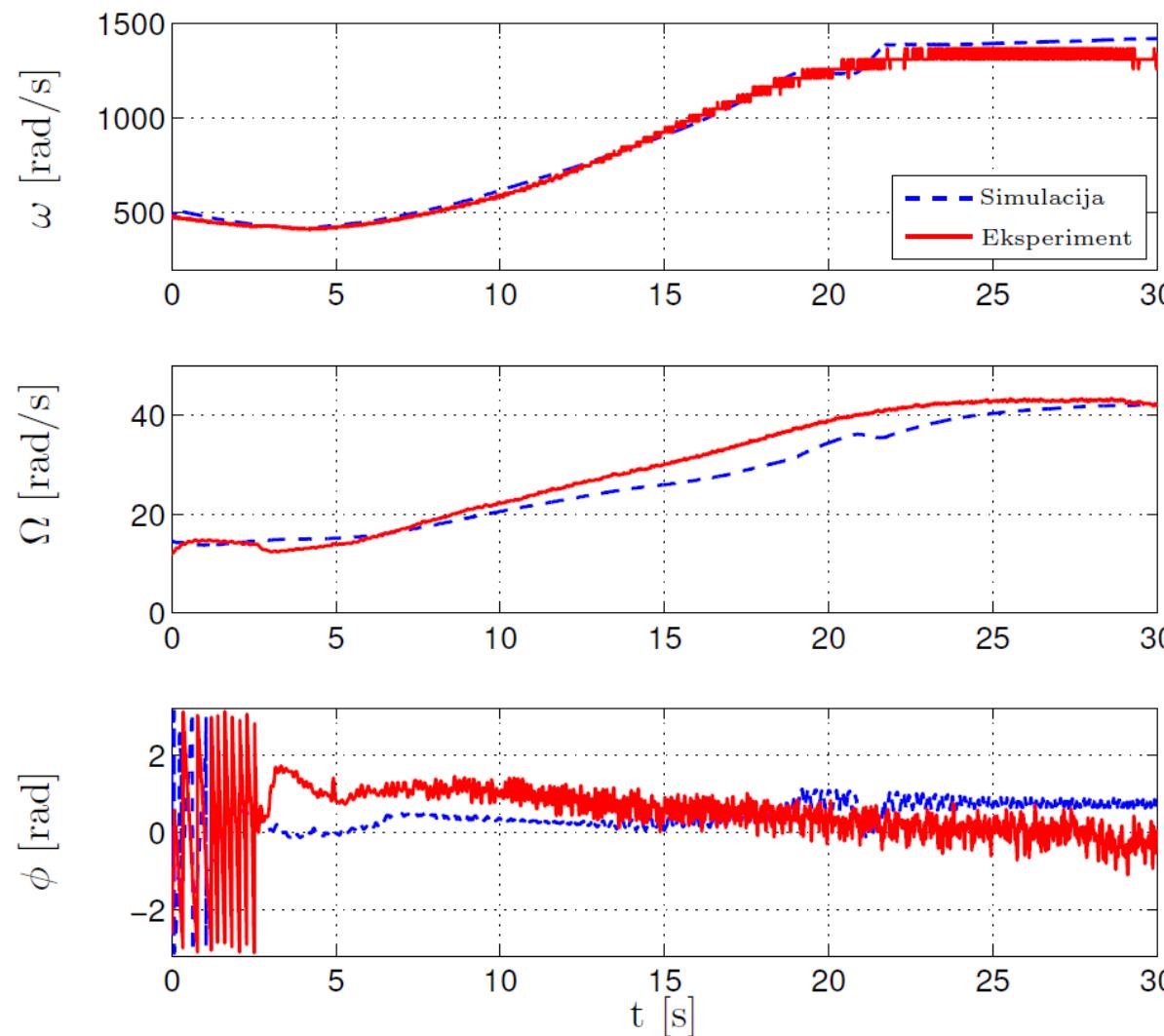
$$v = |\zeta| \dot{\alpha}_3 r_3 + \zeta \dot{\alpha}_4 r_4$$



Eksperimentalni sestav



Robotiziran Powerball



Robotiziran Powerball

ON-LINE FREQUENCY ADAPTATION AND MOVEMENT IMITATION FOR RHYTHMIC ROBOTIC TASKS

Tadej Petrič['], Andrej Gams['], Auke Jan Ijspeert^{*}, Leon Žlajpah[']

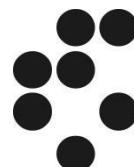
[']Department for Automation, Biocybernetics and Robotics,
Jožef Stefan Institute

^{*}School of Engineering, Institute of Bioengineering,
EPFL - École polytechnique fédérale de Lausanne

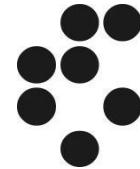
"Accelerating gyroscopic device with the robot"

Multimedia Extension #2

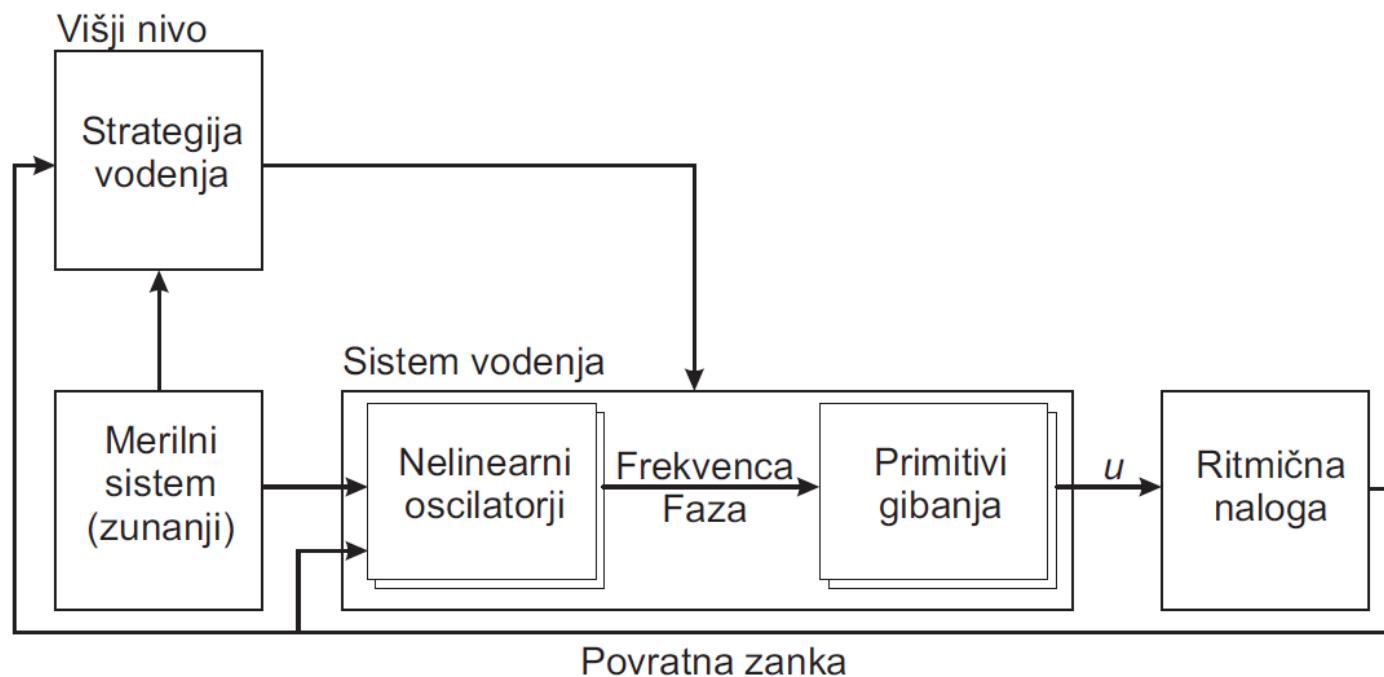
International Journal of Robotics Research



VPELJAVA VIŠJEGA NIVOJA



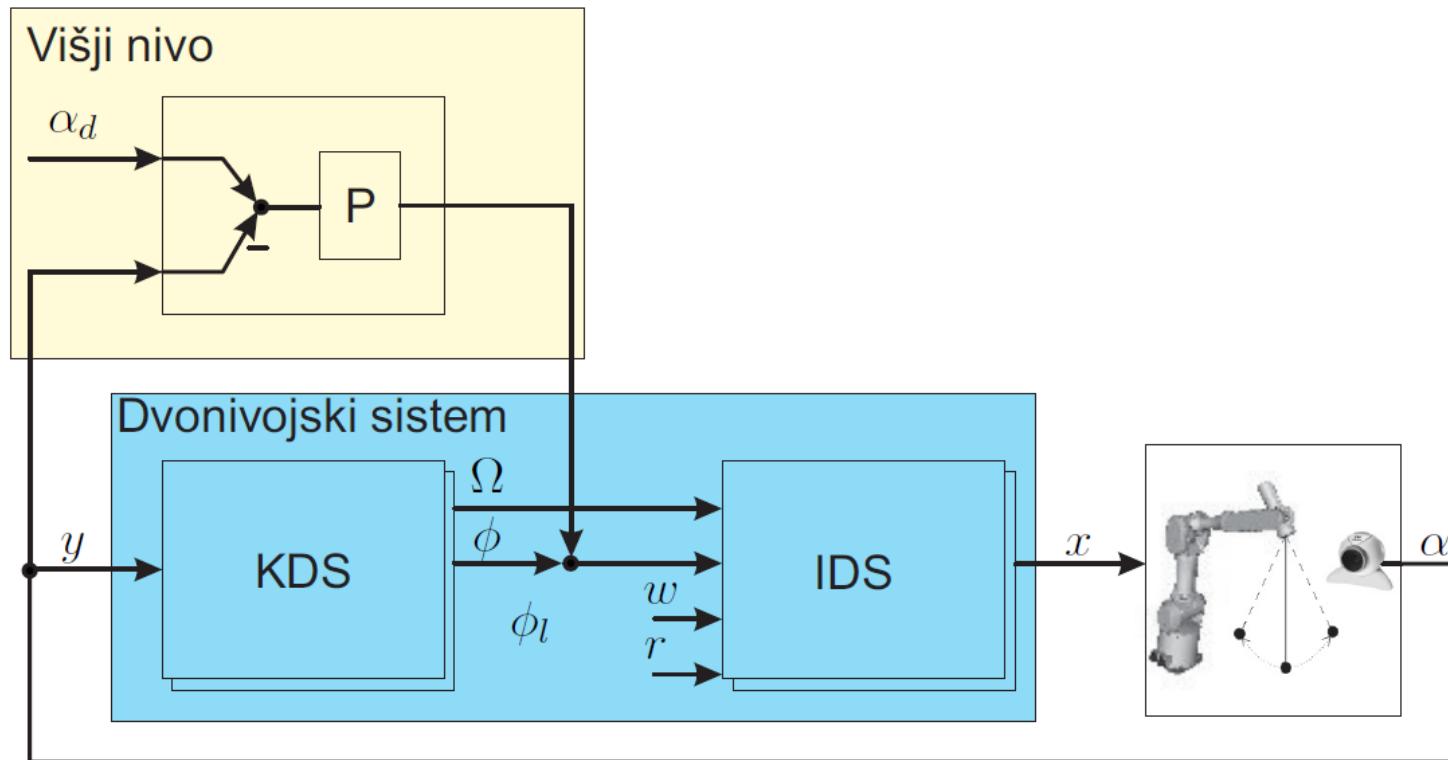
Vpeljava višjega nivoja



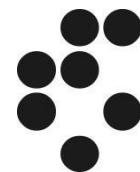
- Primer:
 - Matematično nihalo
 - Sodelovanje človeka in robota pri vrtenju kolebnice



Robotizirano matematično nihalo



Blokovna shema vodenja matematičnega nihala z vključenim višjim nivojem za regulacijo kota nihanja



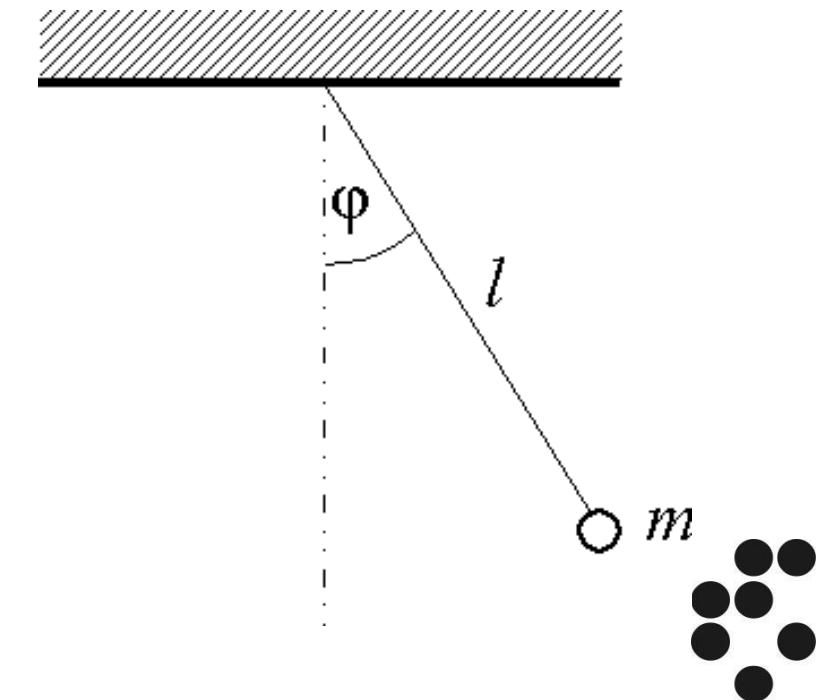
Matematicno nihalo

- Small-angle approximation:

$$T_0 = 2\pi \sqrt{\frac{l}{g}}$$

- Real pendulums are subject to friction and air drag

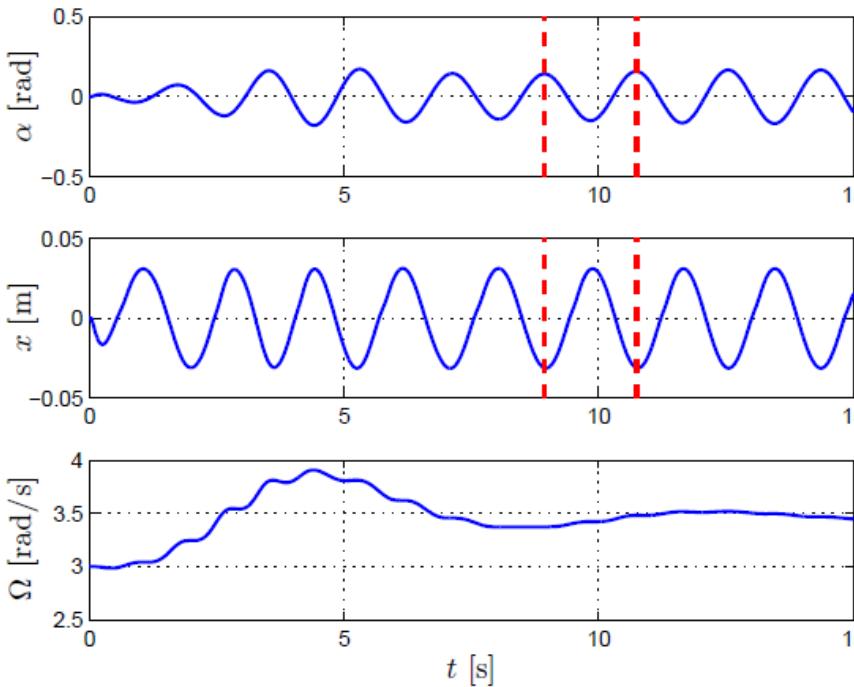
- Goals:
 - Stable oscillation
 - Active dumping
 - Controlling the peak angle



Rezultati

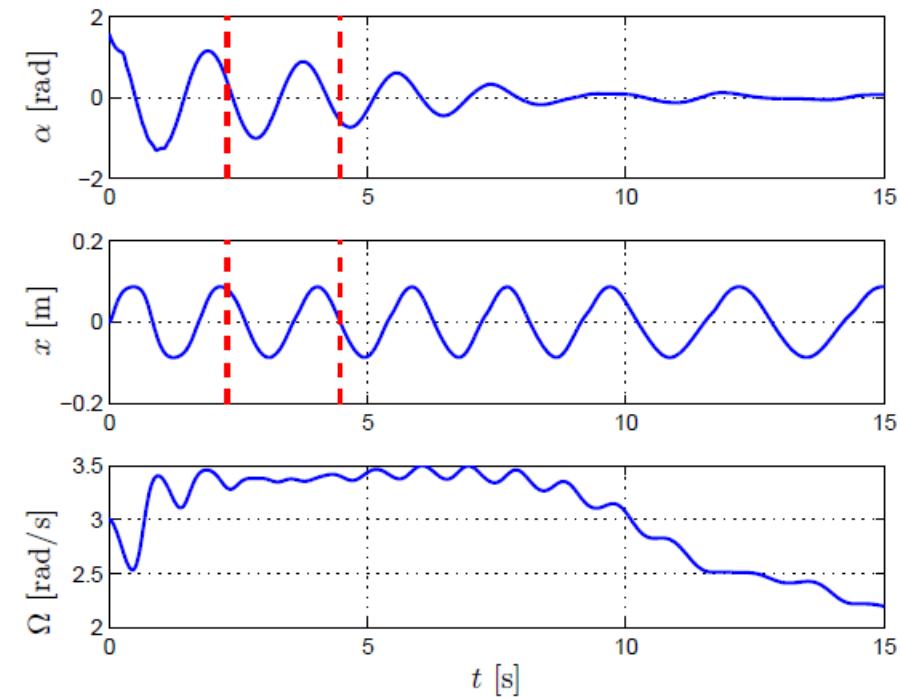
- Stabilno nihanje

$$\phi l = \pi$$

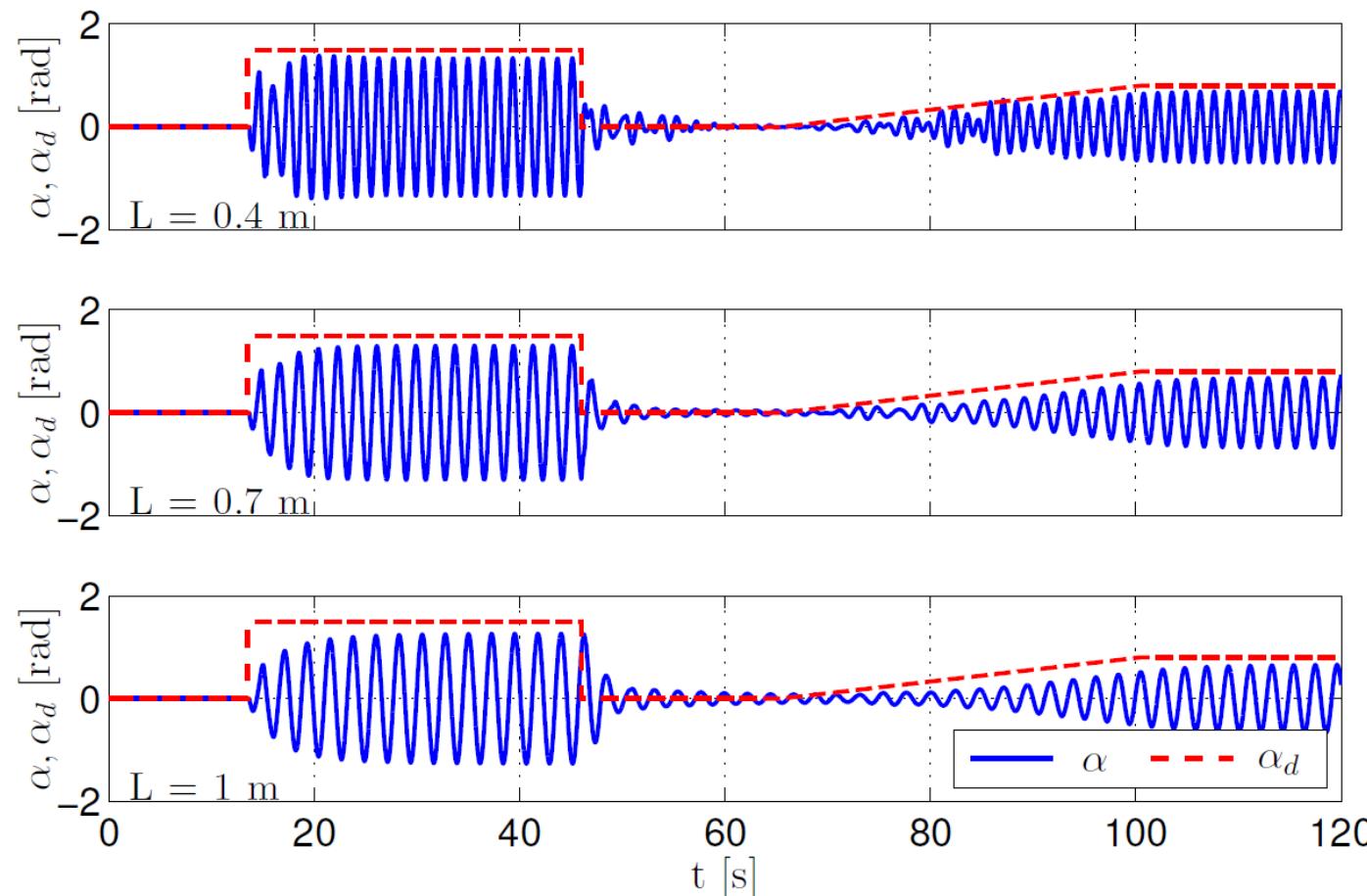


- Aktivno dušenje

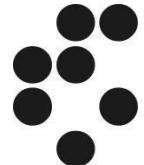
$$\phi l = \pi / 4$$



Rezultati



Rezultati simulacije regulacije kota nihanja identičnega sistema z identičnimi parametri in različno dolgimi nihali



Video



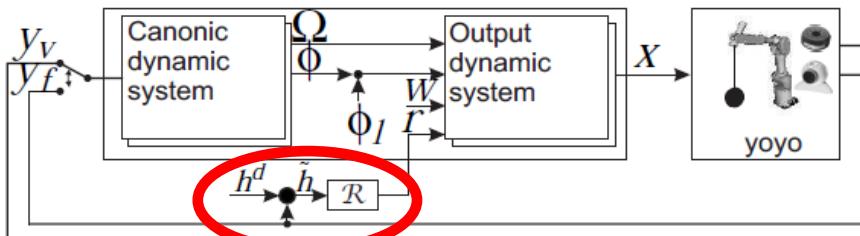
Levo daljša dolžina nihala kot desno.



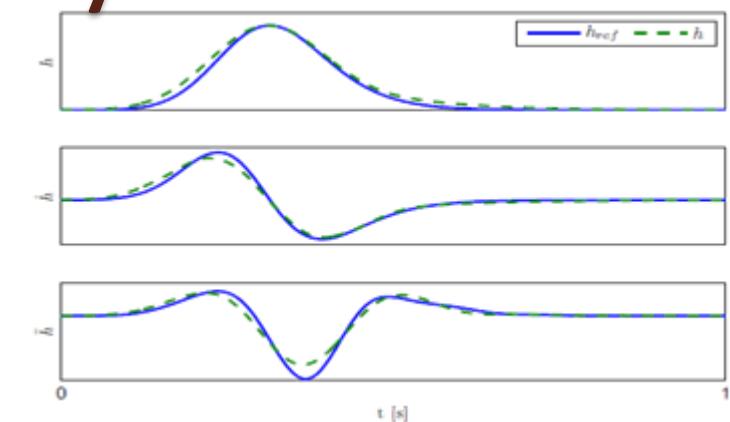
Igranje z igračo yo-yo

- Zahtavna naloga za robota
- Različne možnosti izbire signala za povratno zanko (sila ali robotski vid)
- Regulator višine igranja:

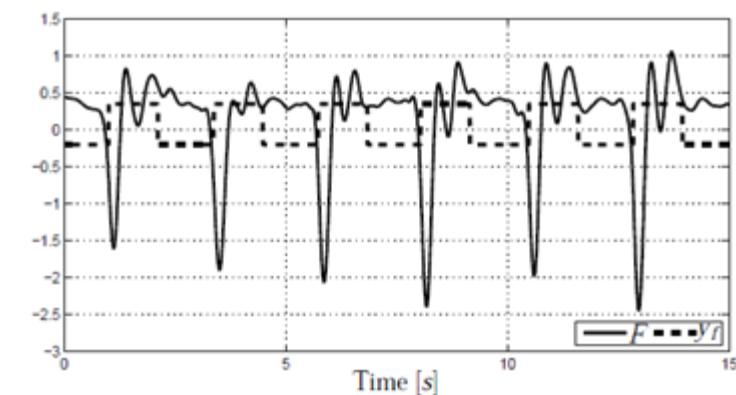
$$r(t) = k_p \tilde{h}(t) + k_i \int \tilde{h}(t) dt$$



Shema vodenja



V naprej definirana oblika trajektorije giba

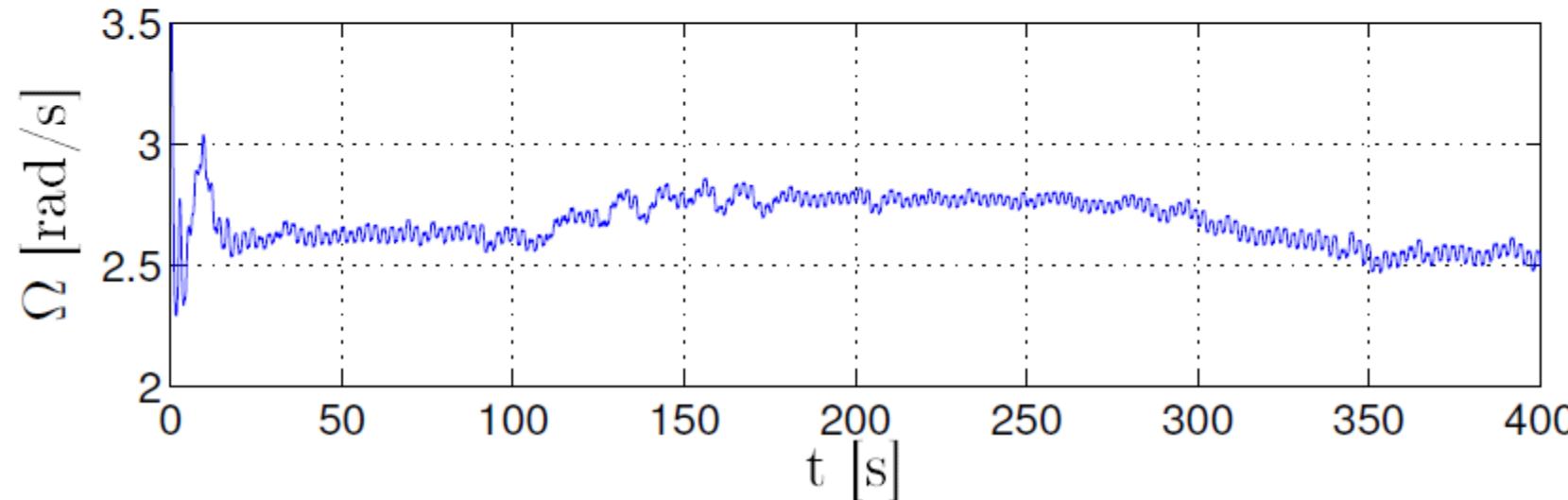
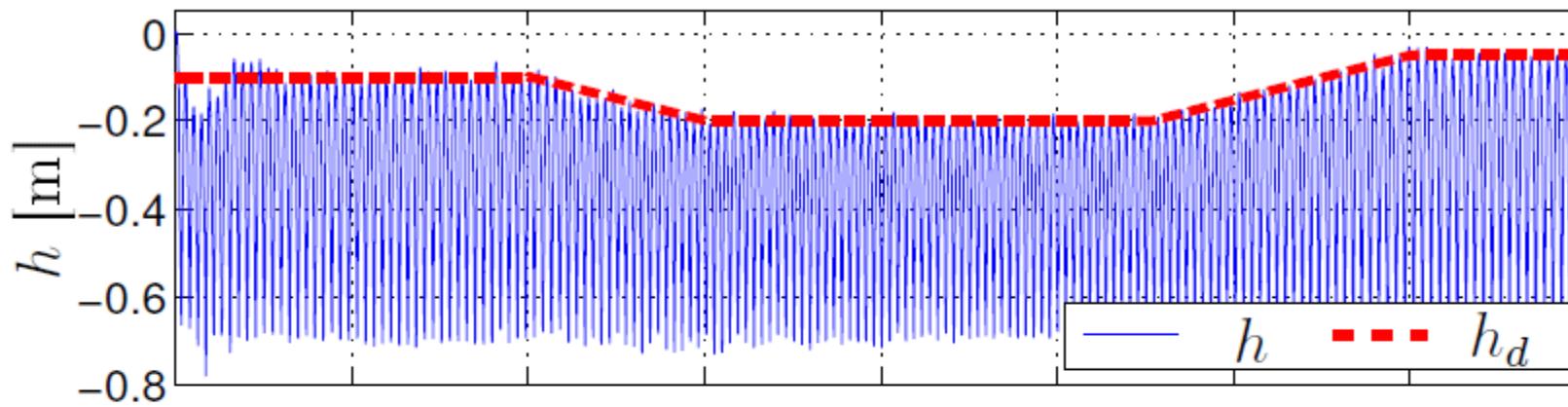


Merjeni signal sile

1. Petrič T., Gams A., Žlajpah L., Frequency extraction based on adaptive fourier series : application to robotic yo-yo, ICINCO 2010



Rezultati



Video

ON-LINE FREQUENCY ADAPTATION AND MOVEMENT IMITATION FOR RHYTHMIC ROBOTIC TASKS

Tadej Petrič['], Andrej Gams['], Auke Jan Ijspeert*, Leon Žlajpah[']

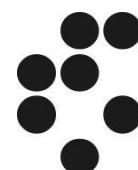
[']Department for Automation, Biocybernetics and Robotics,
Jožef Stefan Institute

*School of Engineering, Institute of Bioengineering,
EPFL - École polytechnique fédérale de Lausanne

"Playing yo-yo with either the force feedback or the visual
feedback"

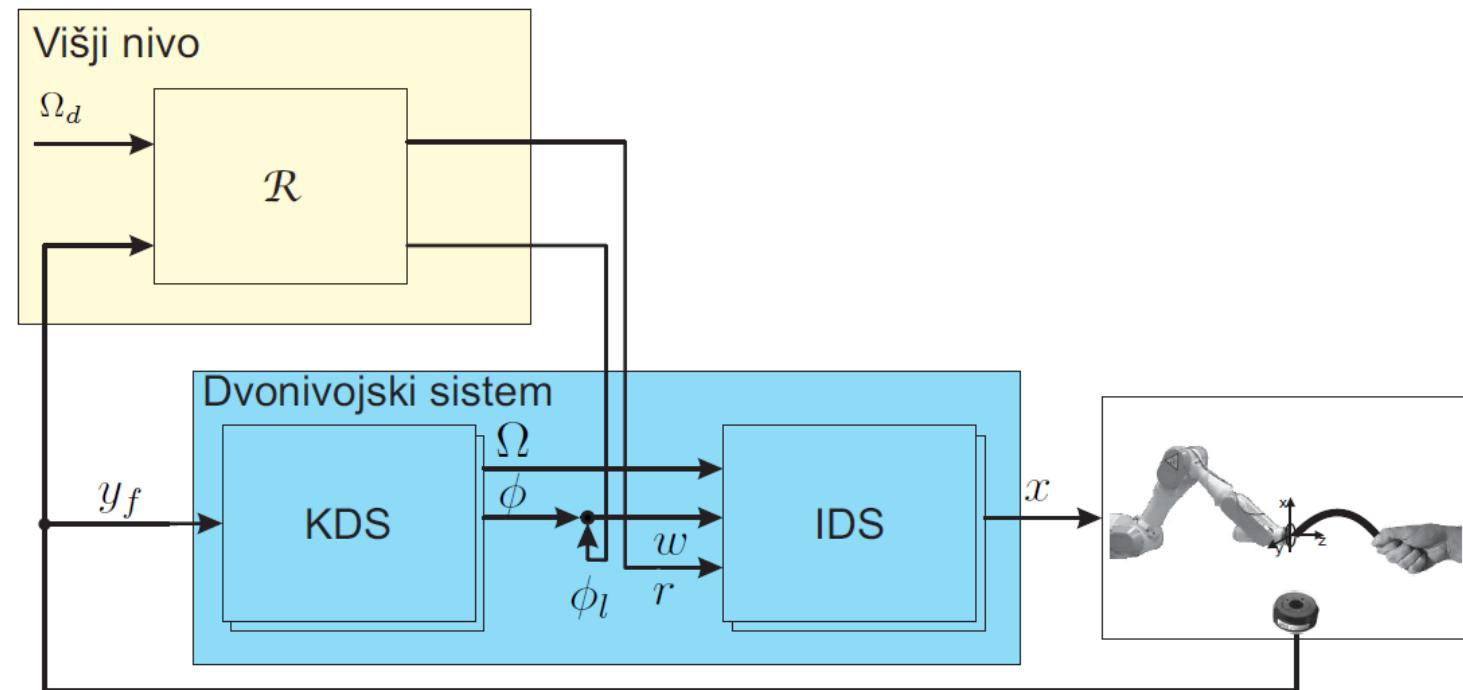
Multimedia Extension #1

International Journal of Robotics Research



Sodelovanje robota in človeka pri vrtenju kolebnice

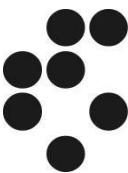
- Hitrost vrtenja je odvisna od gibanja človeka
- Določanje smeri vrtenja: $\dot{\phi}_l = P(\phi_x - \phi_y - \phi_l)$
- Regulacija hitrosti vrtenja: $r = K_p(\Omega_d - \Omega) + K_i \int (\Omega_d - \Omega)$



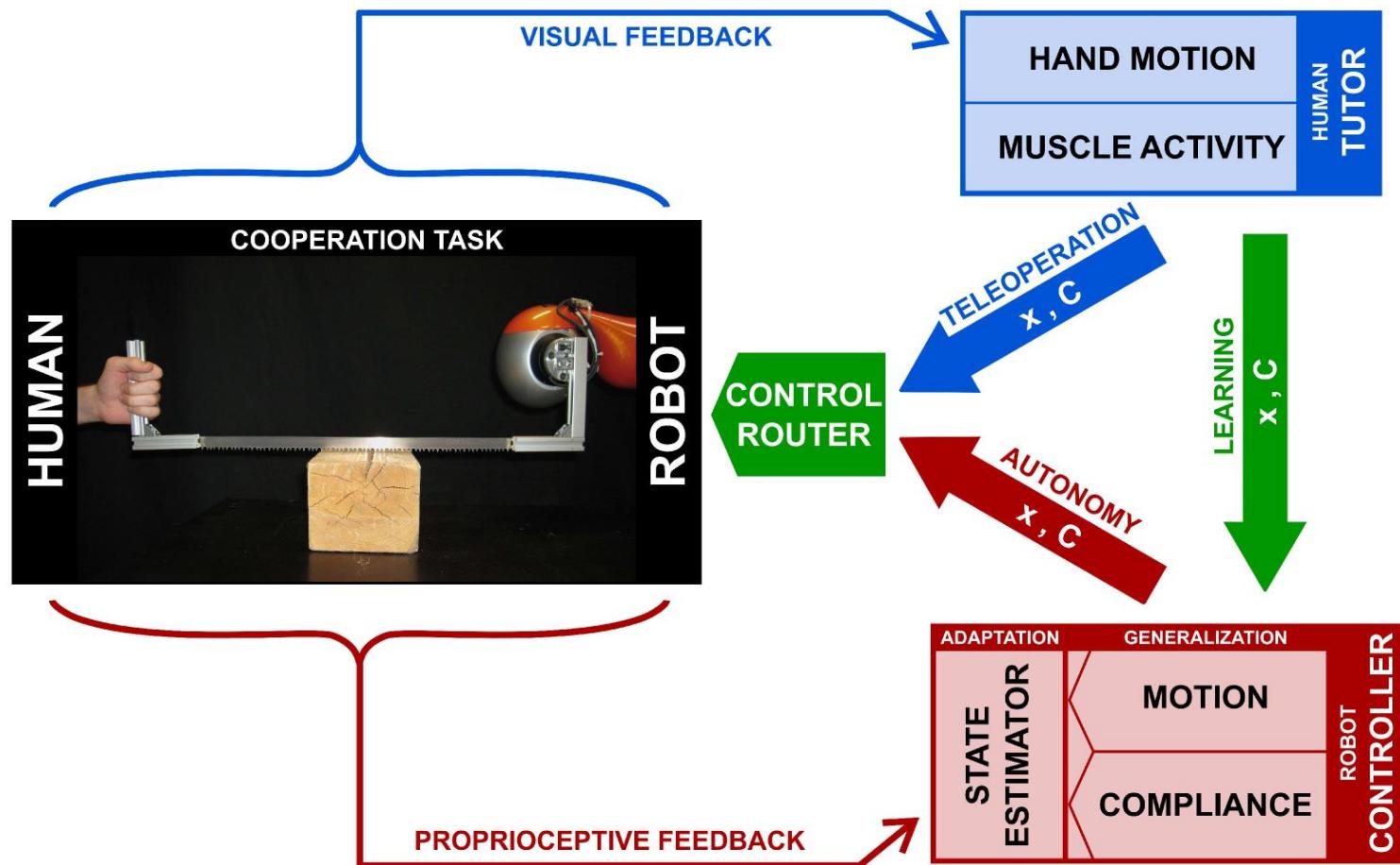
Vrtenje kolebnice

Summary

This video shows cooperative rope turning by a human and a robot.



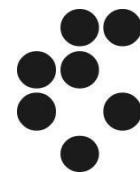
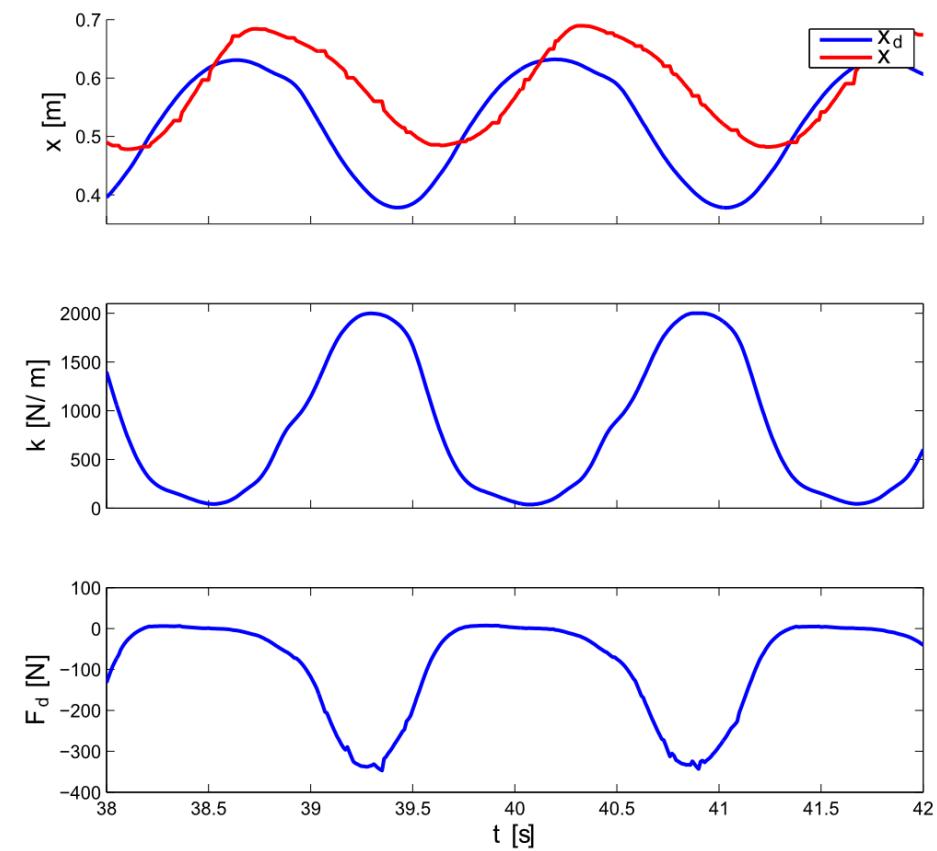
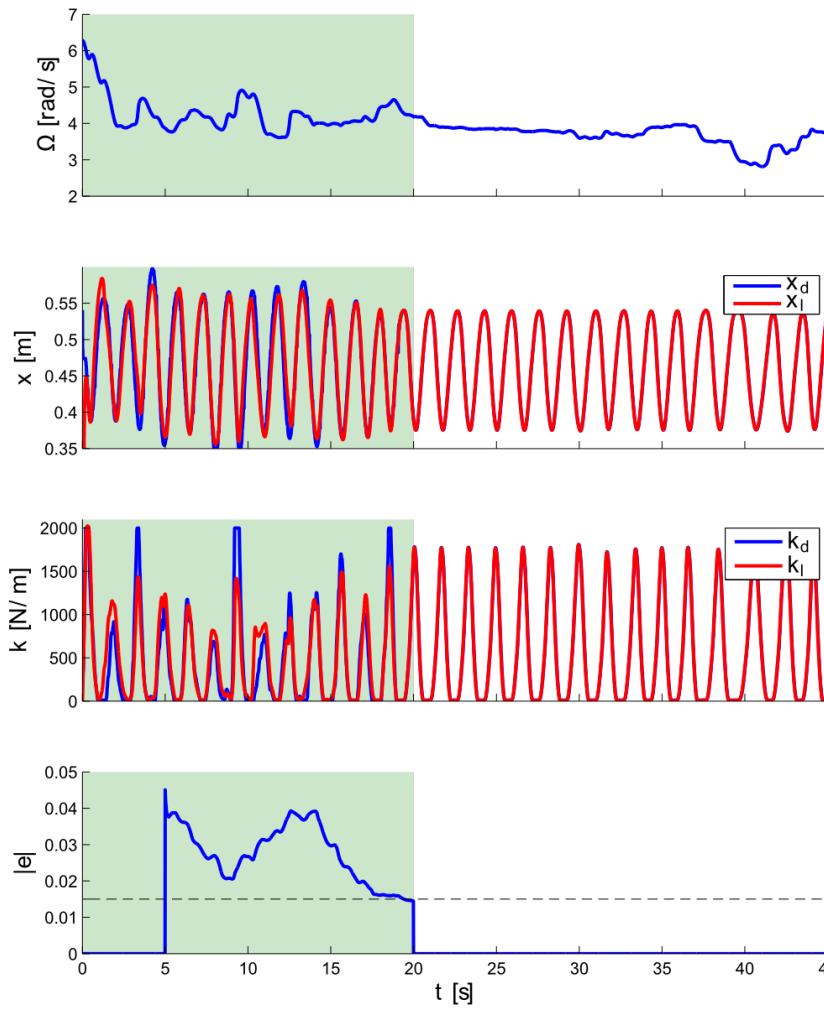
Sodelovanje robota in človeka pri žaganju



Žaganje



Cooperative sawing



SPROTNO PRILAGANJE Z VPELJAVO ČLOVEKA V POVRATNO ZANKO



Sprotno učenje in spreminjanje že naučenih gibov

- Nov pristop spreminjanja obnašanja robota z vpeljavo človeka neposredno v povratno zanko vodenja
- Učitelj lahko neposredno določi želene spremembe gibanja z ukazi
- Za zajemanje ukazov učitelja uporabimo Microsoft Kinect RGB-D kamero



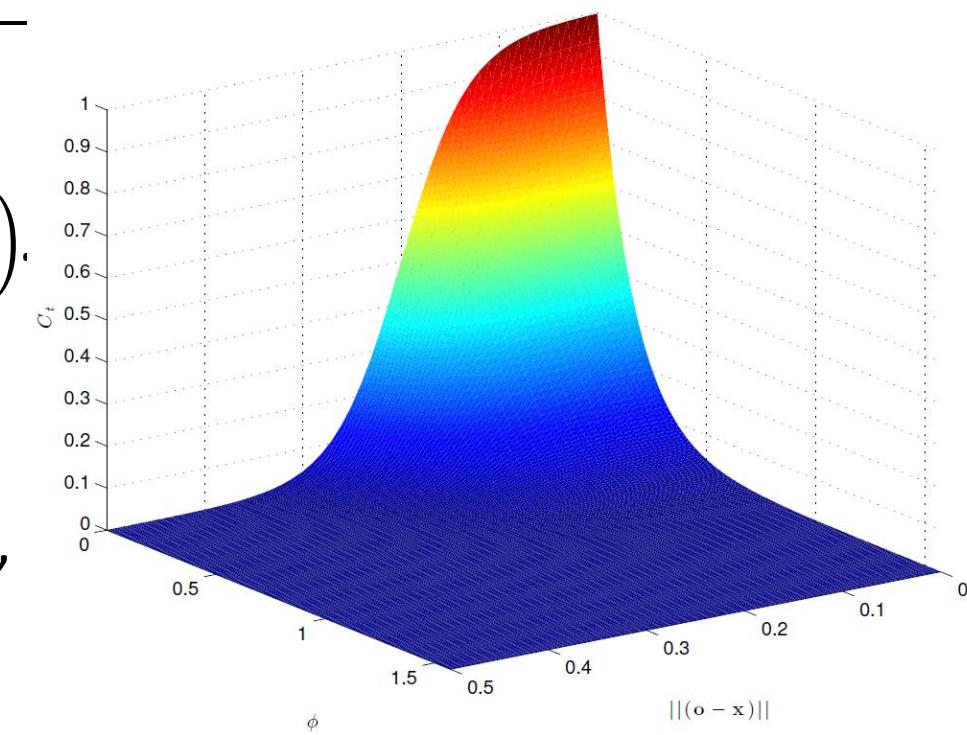
Sistem

- Temelji nelinearnimi oscilatorji
 - $\dot{\phi} = \Omega - K \sin(\phi)$,
 - $\dot{\Omega} = -K \sin(\phi)$,
- in izhodnem dinamičnem sistemu
 - $\dot{z} = \Omega (\alpha (\beta g(y) - y) + f) + C_y f$,
 - $\dot{y} = \Omega z$,
- kjer dodatno vpeljemo člen C_y , ki omogoča sprotno prilagajanje.



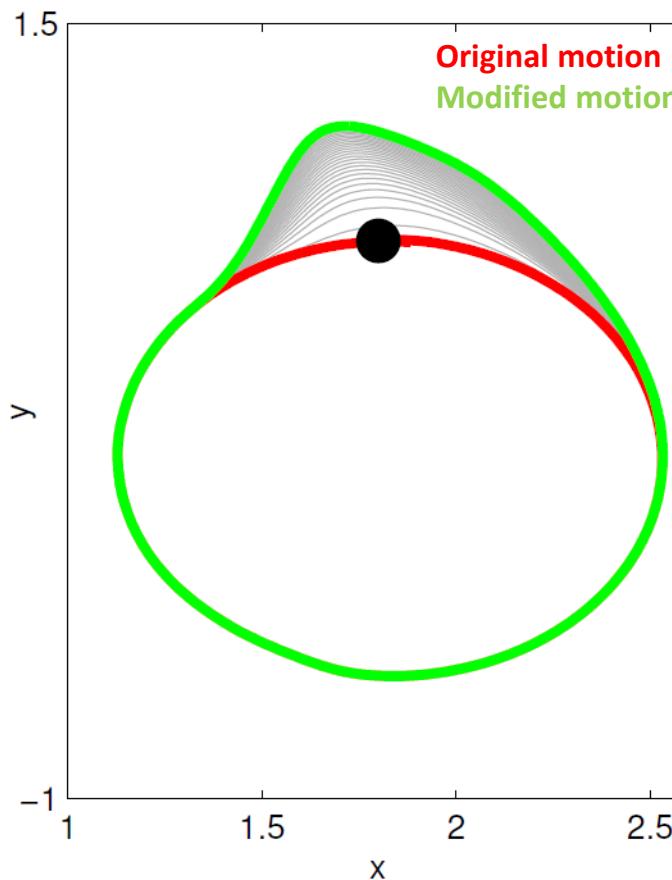
Potencialna polja

- Člen C_y ki omogoča učitelju spreminjanje gibanja je definiran kot
 - $C_y = \gamma s(\|o - x\|) \exp(-$
 - $s(r) = \frac{1}{1+e^{\eta(r-r_m)}},$
 - $\phi = \arccos \left(\frac{(o-x)^T \dot{x}}{\|o-x\| \| \dot{x} \|} \right).$
- Primer z parametri:
 $\eta = 30, r_m = 0.2, \gamma = 1,$
in, $\beta = -20/\pi$

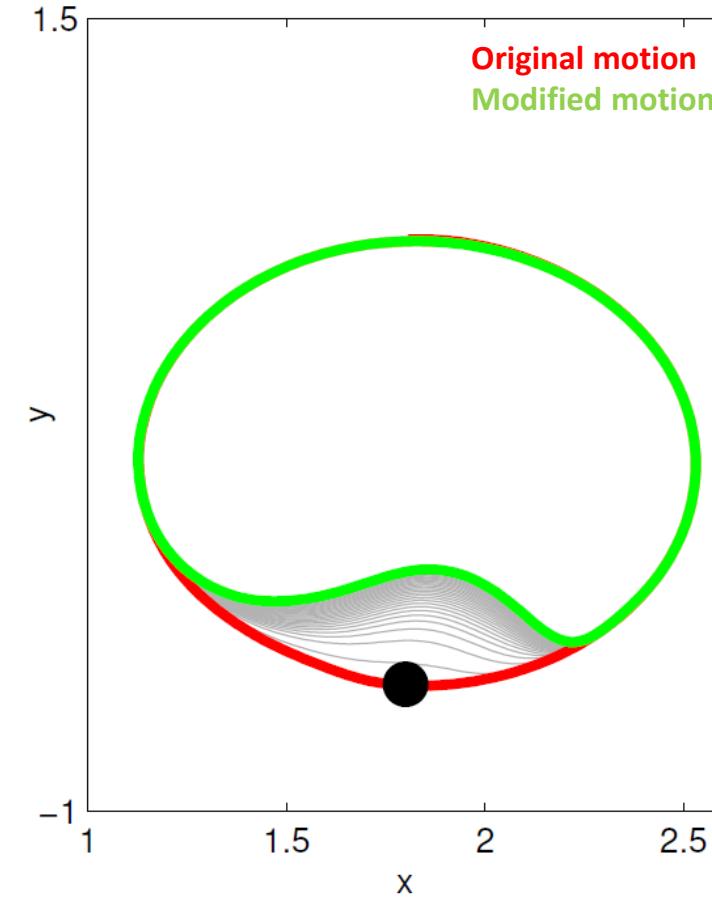


Simulacijski primeri

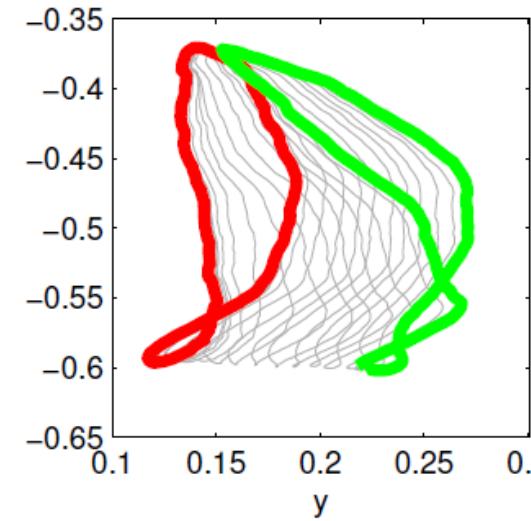
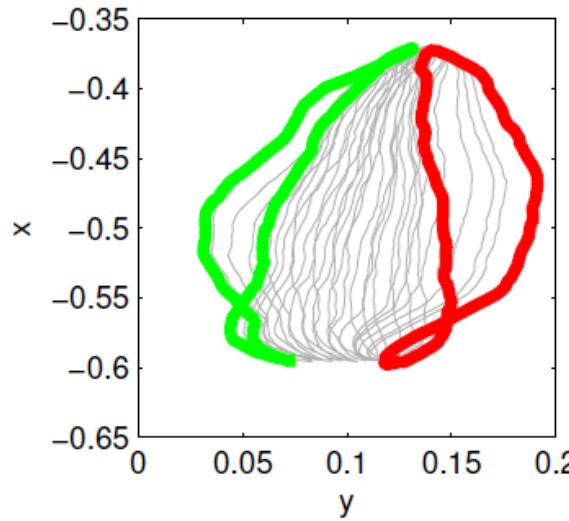
Pushing out



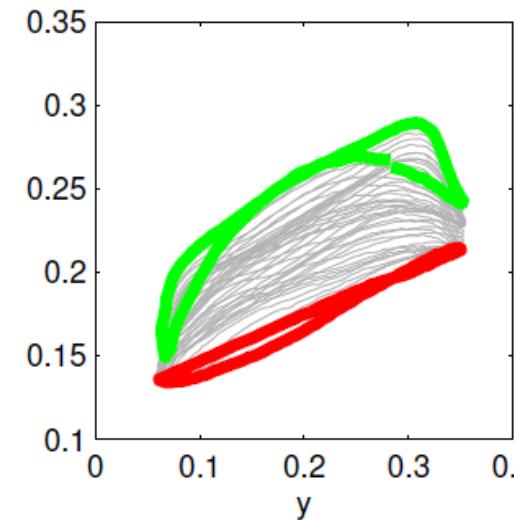
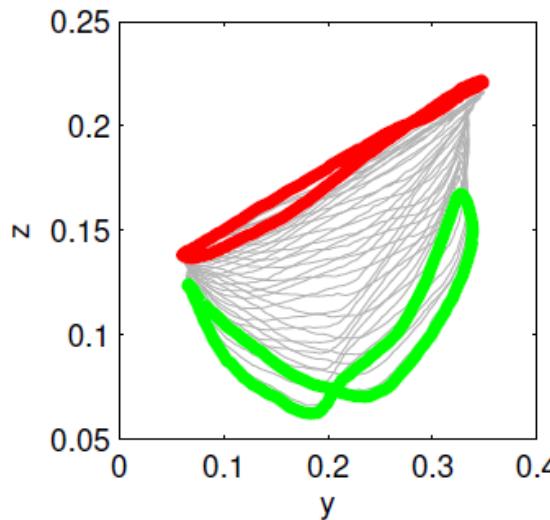
Pushing in



Primer na humanoidném robotu Cb-i



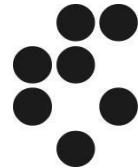
Original motion



Modified motion

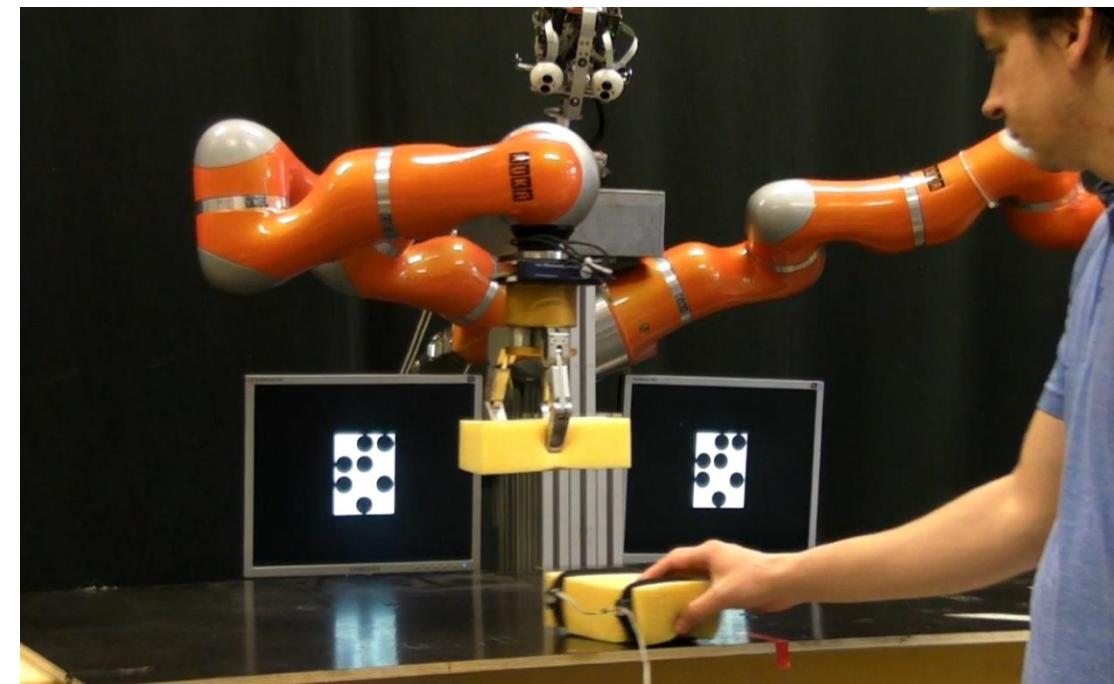


Video

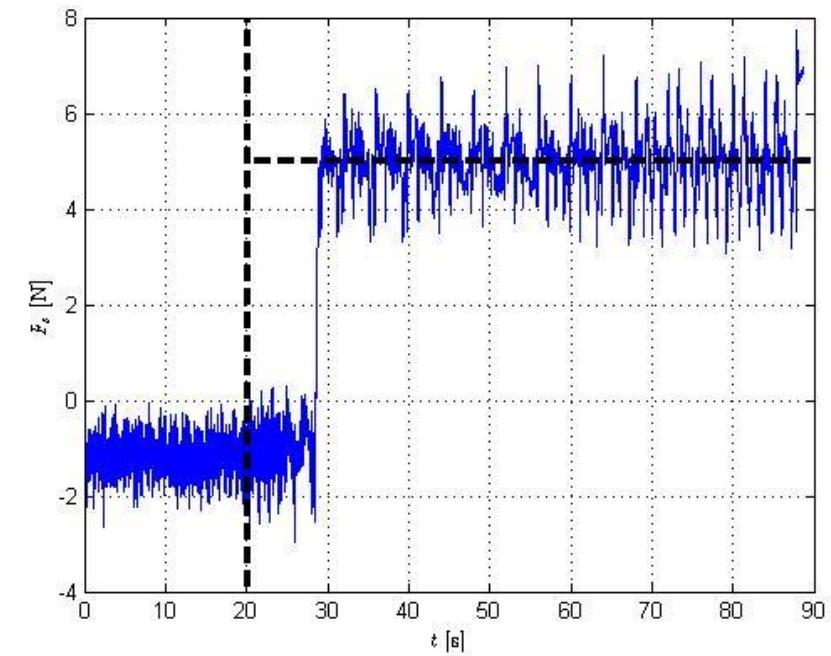
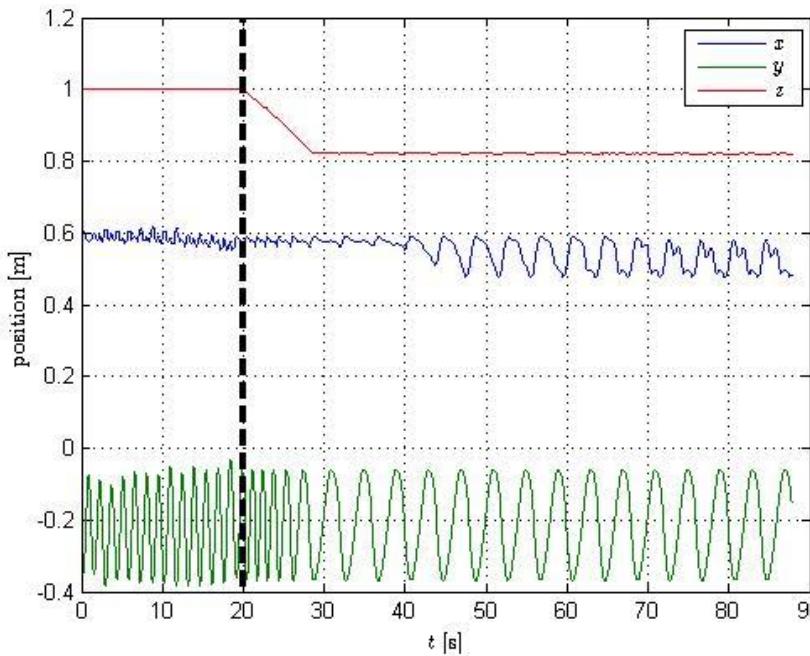


Učenje brisanja mize

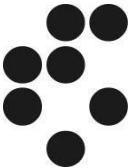
- Učenje trajektorije v realnem času
- Z uporabo sil in navorov v sistemu vodenja zagotovimo kontakt z mizo.
- Trajektorijo lahko učitelj spremeni z uporabo sistema robotskega vida ali s pritiskom na robota



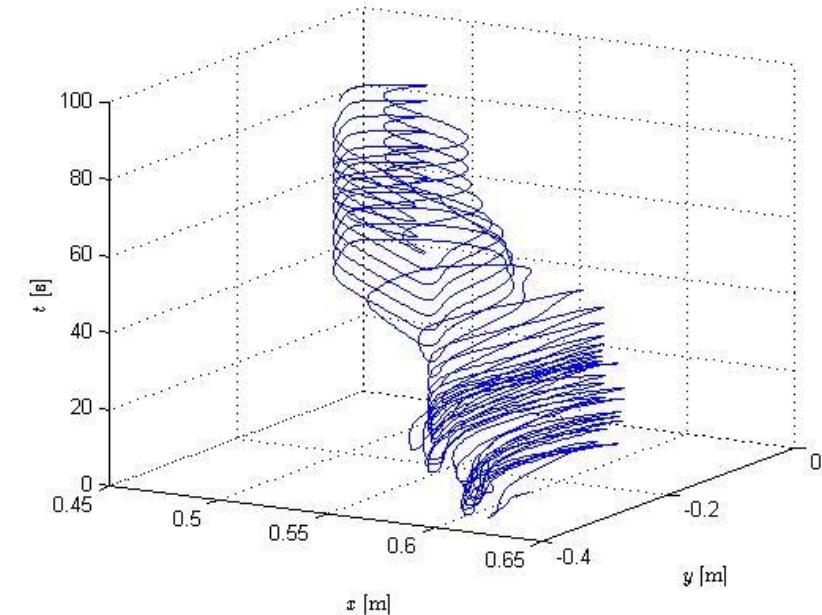
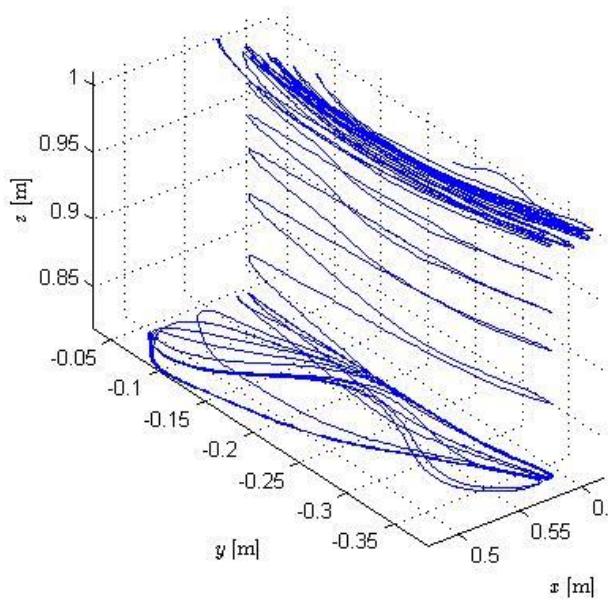
Rezultati učenja in spreminjanja giba



Trajectories of motion (left). Wiping is learned just over 20s. After learning, the frequency is reduced in order to safely find contact ($y = \text{green}$). Height is reduced to achieve contact (red). Forces of interaction (right), desired force = 5N.

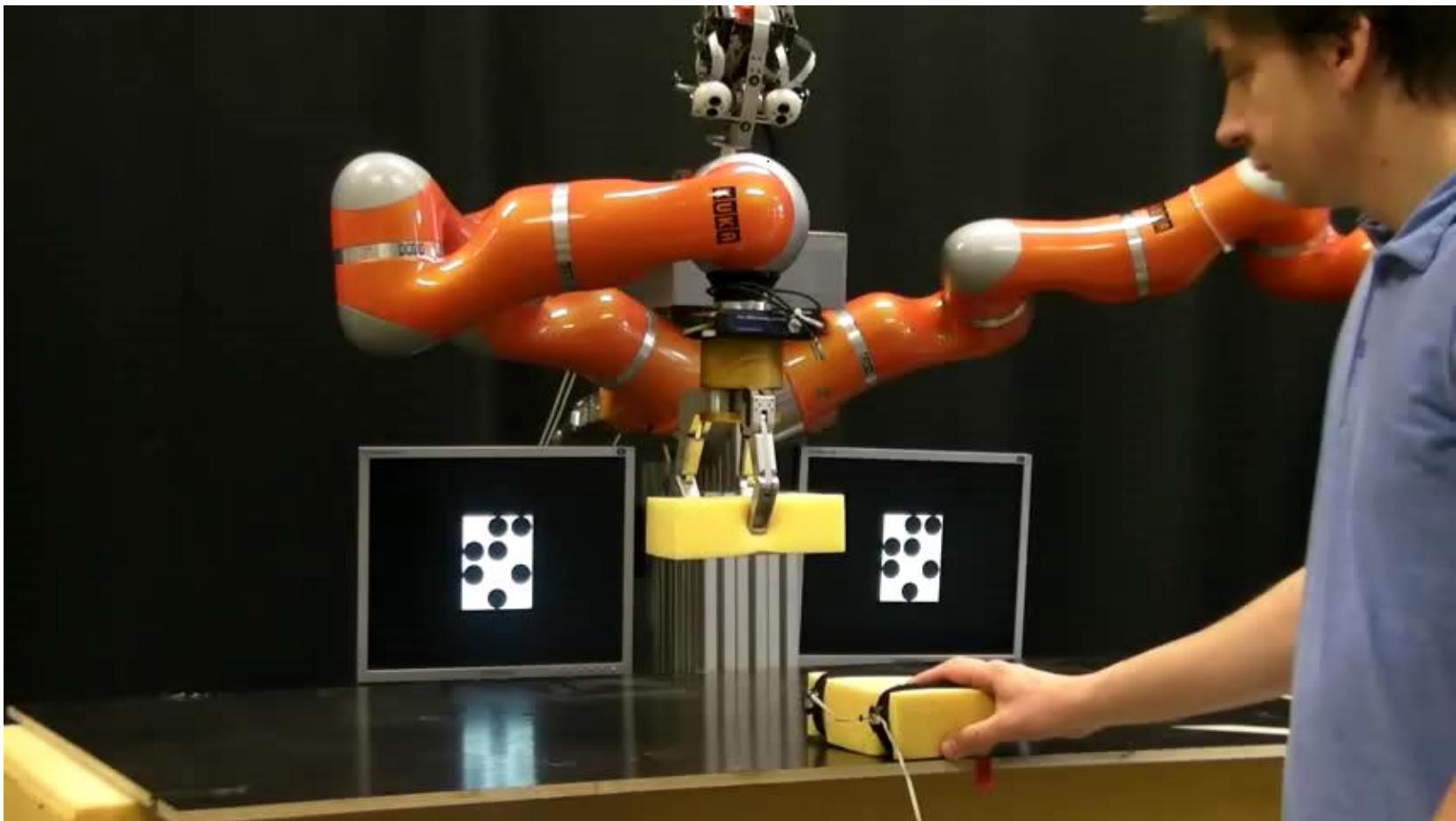


Rezultati brisanja mize v 3D



X-Y-Z trajectories of motion on the left. After learning at the same height, the robot descends to find contact. The trajectory is changed with coaching. On the right, the X-Y trajectory, with T over time, During learning the trajectory is roughly constant, it is later changed with coaching..





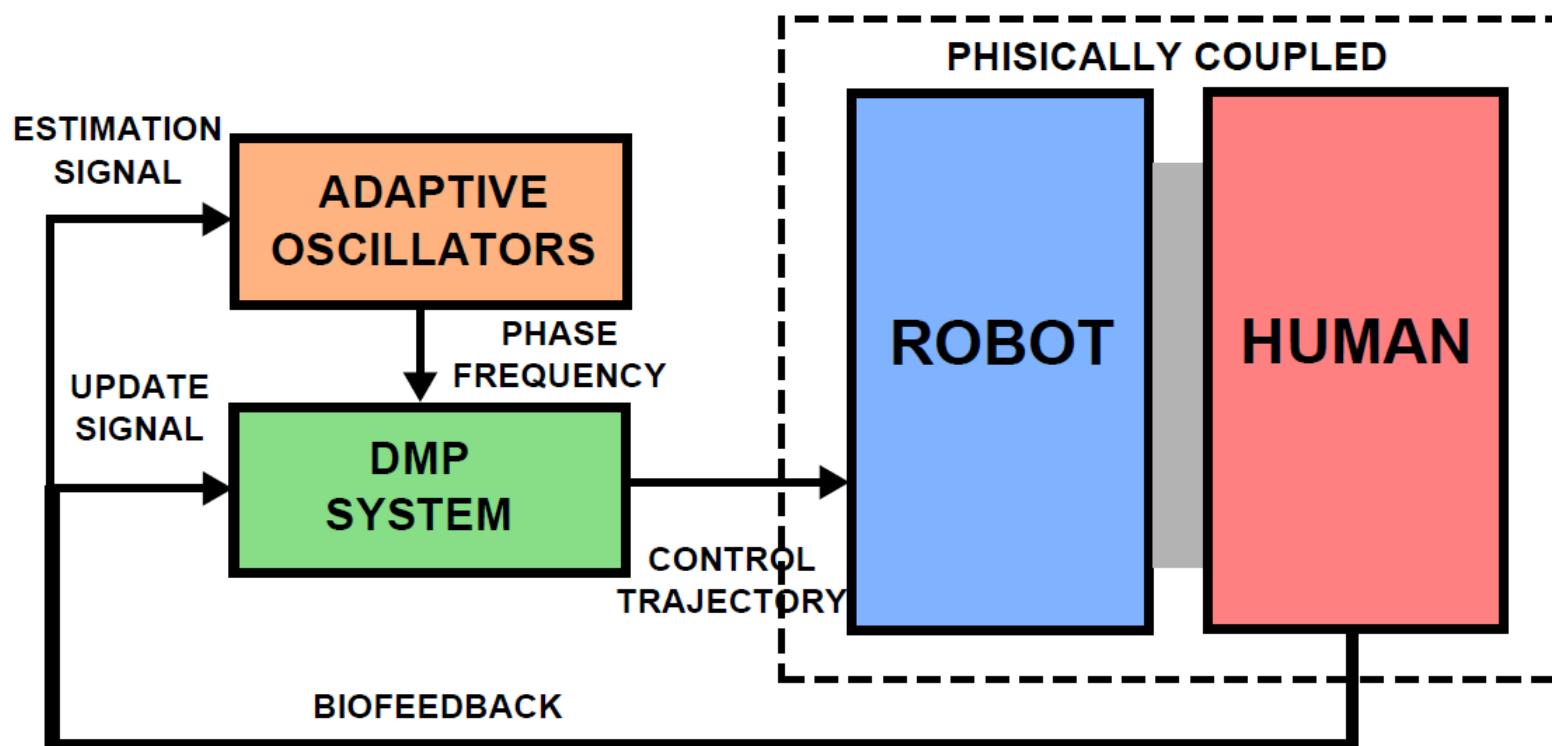
Vodenje robotskega eksoskeleta

- Minimizacije mišične aktivnosti s spotnim prilagajanjem izhodnega dinamičnega sistema
- Mišično aktivnost merimo na antagonističnih parov mišic v vsakem sklepu z uporabo EMG-ja
- EMG signali so normalizirani s pomočjo metode Maximal Voluntary Contraction (MVC) [Yang et al., 1986]
- Signal, ki prilagaja izhodni dinamični sistem za vsak sklep posebej je sestavljen iz razlike mišične aktivacije

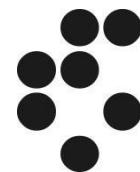
$$U_{FB}(t) = G_{FB}(A_{FLEX}(t) - A_{EXT}(t))$$



Vodenje robotskega eksoskeleta



Shema vodenja



Video

