Identification and Design of Neuromorphic Controller Inspired by Mammalian Neural Control Mechanisms Applying Concurrent Learning Algorithm

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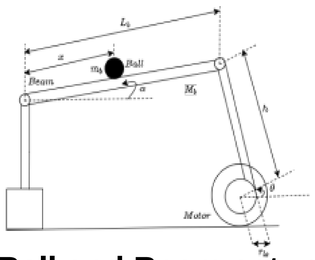
Problem Statement

- Nervous system frameworks preserve strong and adaptable control whilst adapting to instability of their components.
- Ability to identify and replicate these neuromorphic control systems could help reproduce the functional capabilities to yield better results in a lot of real-time applications.
- As an evidence, a neuromorphic controller is designed based on teachings from a human expert on a class of ball and beam non-linear system.

Design and identification of controller



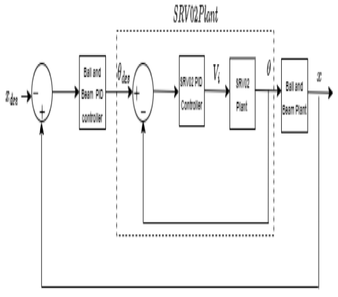
Ball and Beam setup

Modelling of ball and beam

- Four different states of the system are $(x_1, x_2, x_3, x_4) = (\theta, \dot{\theta}, x, \dot{x})$ with θ- angle of beam and x-position of the ball.
- System is simulated in discrete-time with the state-equations as,

$$x_1(k+1) = x_1(k) + T_s * x_2(k)$$
$$x_2(k+1) = x_2(k) + T_s * \left(\left(-36.5592 * x_2(k)\right) + \left(55.8659 * u(k)\right)\right)$$
$$x_3(k+1) = x_3(k) + T_s * \left(x_4(k)\right)$$
$$x_4(k+1) = x_4(k) + T_s * (0.0025454 * x_3(k) * x_2(k)^2 - 7 * sin(0.0596 * x_1(k)))$$

Concurrent learning for identification



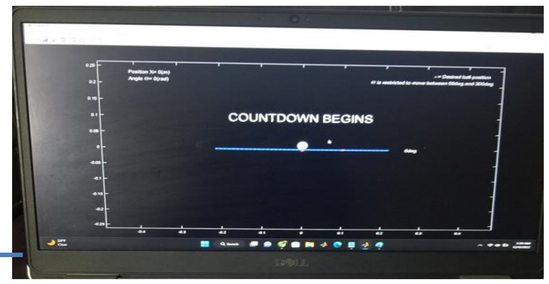
Two-Loop controller of the Ball and Beam system

- **Assumption:** Controller assumed to have structure of a PID
- Human subjects control "θ" based on $x_3(k-1)$ such that,
  $e(k) = x_3(k) - desired\ position\ of\ ball = 0$
- **Recorded data:** angle θ, x_1, x_2, x_3, x_4 and e.
- Since θ tracks desired θ the outer loop control running in the human's brain is modelled as
  $u(k+1) = [K_p; K_i; K_d]^T [e(k); e_{int}(k); e_{dot}(k)]$
  where, u(k) is the controller to be identified.

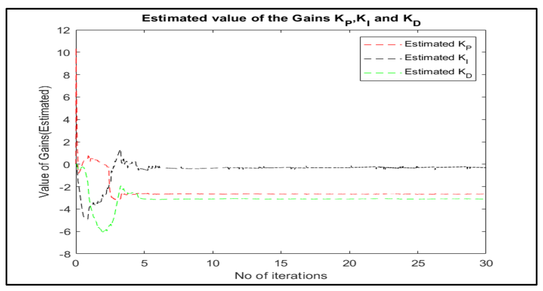
Recorded data

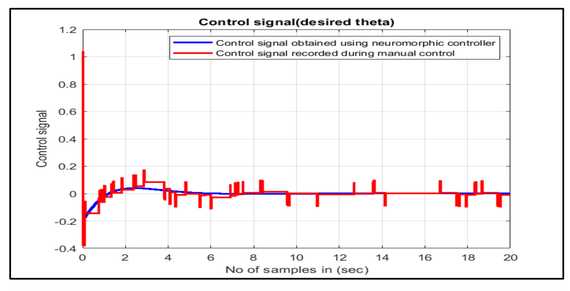
Experiment

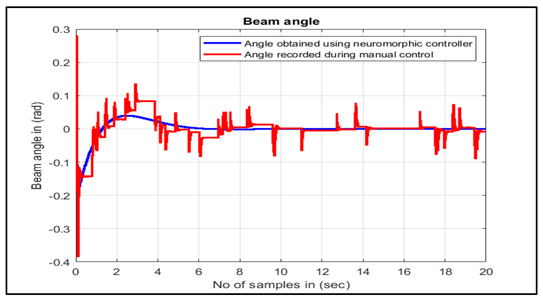
- A GUI of the ball and beam system is developed, and the screen provides the visual feedback to exercise control using mouse.

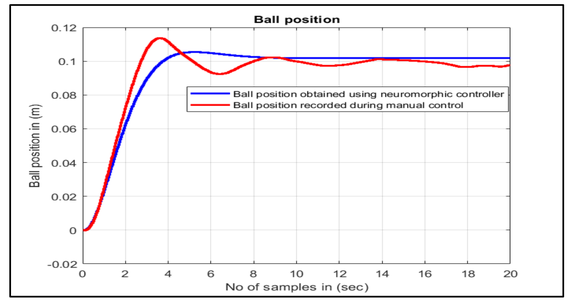


Mouse	Control action
Below the center	Beam and Ball down
Above the center	Beam and Ball up









Conclusion and Future Work

Estimated Gains

Kp	-1.7946
Ki	-0.0213
Kd	-3.0362

MSE values of manual and estimated controller

MSE Values	States and control signal
$2.4e^{-03}$	Control signal (desired theta)
$4.28e^{-05}$	Position of the ball
$7.21e^{-04}$	Angle of the beam

- From the MSE values it is clear that the human controller has been successfully identified and designed assuming a PID structure.
- In future, other controller structures would be considered and the implementation would be done on a physical system for better results.