Tech Documentation: Neurocontrol

Inspired by the Bang Bang controller derived by Lakatos et al. (2013), that is able to extract and drive a motion of a system along that system's eigenfrequency in a very energy efficient manner, the question arose if the human applies a similar strategy to control the body's movement. Stratmann et al. (2016) derived based on this control theory, a possible bio-plausible control strategy of the human brain. The motion of each joint triggers the activity of different proprioceptive neuron pools. The proprioceptors trigger the raphe nuclei in the brain stem to release serotonin into the spinal cord. In turn, the released serotonin increases the excitability of motoneurons of the moving joint and thus, leads to a scaling of the control signal. An overview of this control feedback loop taken from Stratmann et al (2016) is depicted below:

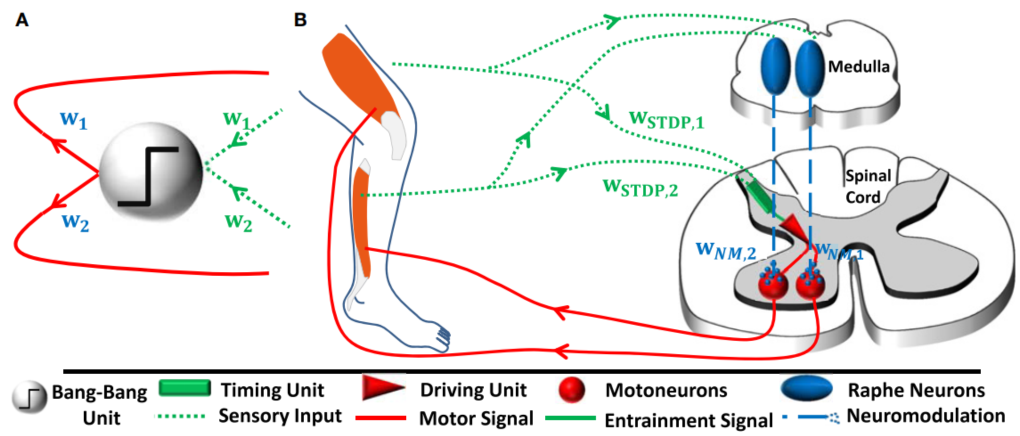
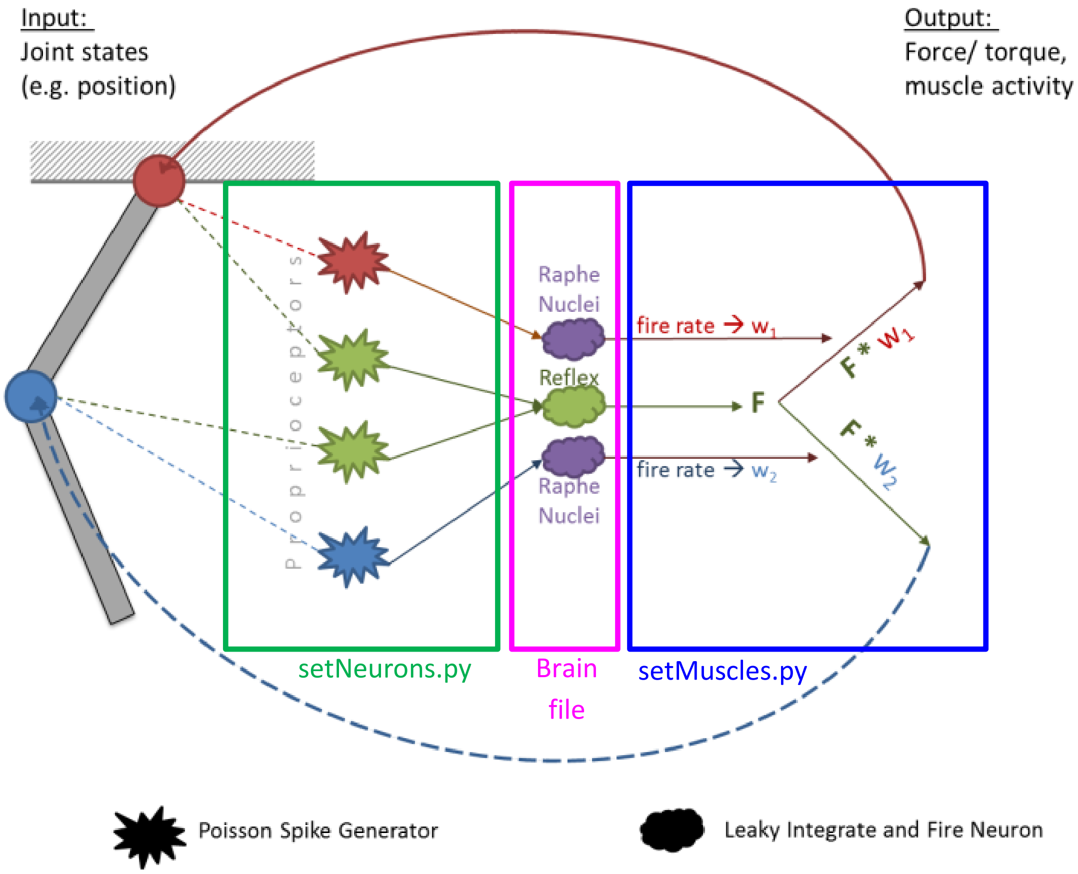


FIGURE 1 | (A) In the mathematical controller design as proposed by Lakatos et al. (2013b), sensory input from each joint *i* is transformed into a one-dimensional coordinate space. For this purpose, the sensory inputs are multiplied by weights w_i. The input entrains a thresholding bang-bang unit, which produces a motor signal. The driving signal is transformed back into the original joint space via the same respective weights. The output transformation accomplishes correct relative force weighting of the individual joints (Figure based on Lakatos and Albu-Schäffer, 2014a). **(B)** In our hypothetical neural controller implementation, sensory input from the joints also converges. The synaptic weights $w_{STDP,i}$ change according to spike-timing-dependent plasticity. We emphasize that the bang-bang controller can be separated into two functionally distinct unit: A timing unit entrains a driving unit, which sends motor signals to muscles innervating all joints involved in a given periodic movement. While functionally distinct, these units do not have to be spatially separated in general. In our model, a single pool of reflex interneurons represents both units and outputs correctly timed motor signals. A parallel, joint-specific, sensory feedback pathway via raphe nuclei releases serotonin into motorpools. This amplifies the common motor output by $w_{NM,i}$ and increases the relative strength of muscles that are more involved in the movement.

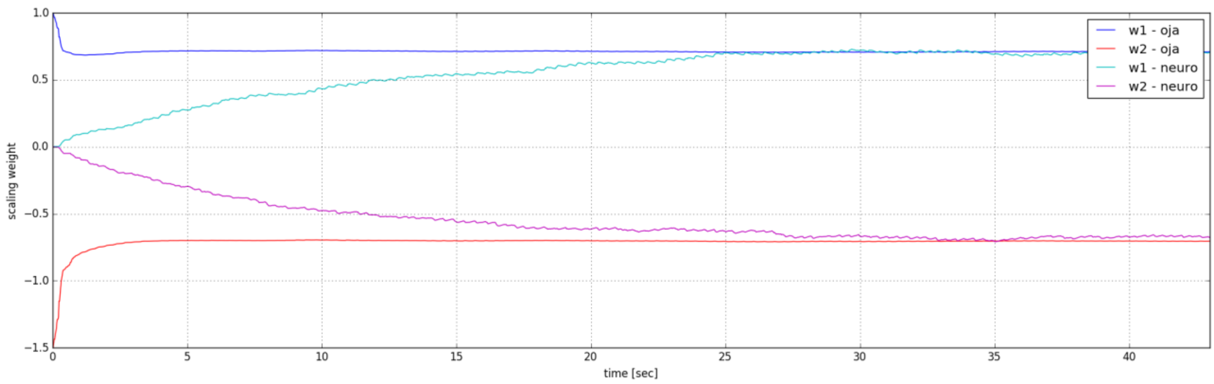
For detailed information of the derivation of this theory, please refer to the stated references.

The neuro controller as described in detail in Stratmann et al (2016) was implemented in the NRP, making use of the spiking neural network implemented via PyNN. In the brain file, three neuron pools are defined: one for each raphe nuclei that map down to the motoneurons of each joint and one combined one which represents the reflex neurons. All are triggered by proprioceptive (Poisson) neurons that fire depending on the joint extension. This is defined in the `setNeuron` function. The spiking of the neural network is read out in the `setMuscles` function to define the weighting of the control signal that is then applied to the two joints of the hopper, which is used in the Default Setup of this experiment.

An overview of how the control cycle is implemented in the NRP is shown in the following



Implementing the neuro controller in the NRP and comparing the results of the tuned weights through the spiking neural network with the weights determined by implementing the bang-bang controller proposed by Lakatos et al. (2013), the findings of Stratmann et al. (2016) can be reproduced. The neuro controller making use of a spiking neural network and the weights determined by using the Oja rule in the bang-bang controller lead to the same values for the weights to scale the control signal that drives the joints (w1 → hip, w2 → knee, see below). Thus, both controllers produce the same motion and limit cycle in a robotic system and open up new hypothesis about the brain control in the field of neuroscience.



To apply the neuro control to a different system, the applied parameters need to be tuned. This includes:

- m_sens : weighting of the proprioceptive sensor neurons
- m_ser : weighting of the neurons mapping to the Raphe Nuclei
- ser_constant : constant serotonin flow
- m_f : weight to tune muscle force
- m_ser : weight to tune serotonin activity

For detailed description of all constants see Stratmann et al (2016).

TIPP for tuning:

When tuning the weightings for a new robotic system, it can be helpful to first apply the BangBang Controller of Lakatos et al (2013) and use it to tune the parameters for the neuro controller.

References

Lakatos, D., Görner, M., Petit, F., Dietrich, A., & Albu-Schäffer, A. (2013, November). A modally adaptive control for multi-contact cyclic motions in compliantly actuated robotic systems. In *2013 IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 5388-5395). IEEE.

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Stratmann, P., Lakatos, D., & Albu-Schäffer, A. (2016). Neuromodulation and synaptic plasticity for the control of fast periodic movement: energy efficiency in coupled compliant joints via PCA. *Frontiers in neurorobotics*, *10*, 2

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