Cerebellar Control for Coordination

Tuomas J. Lukka[1,2] and Harri Valpola[2]
[1] *Zendroid Ltd.*
[2] *Computational Neuroscience Research Group, LCE, TKK*
HELSINKI UNIVERSITY OF TECHNOLOGY
Laboratory of Computational Engineering

Introduction

The cerebellum is known to be responsible for fine-tuning and coordinating complex movements in mammals[1].

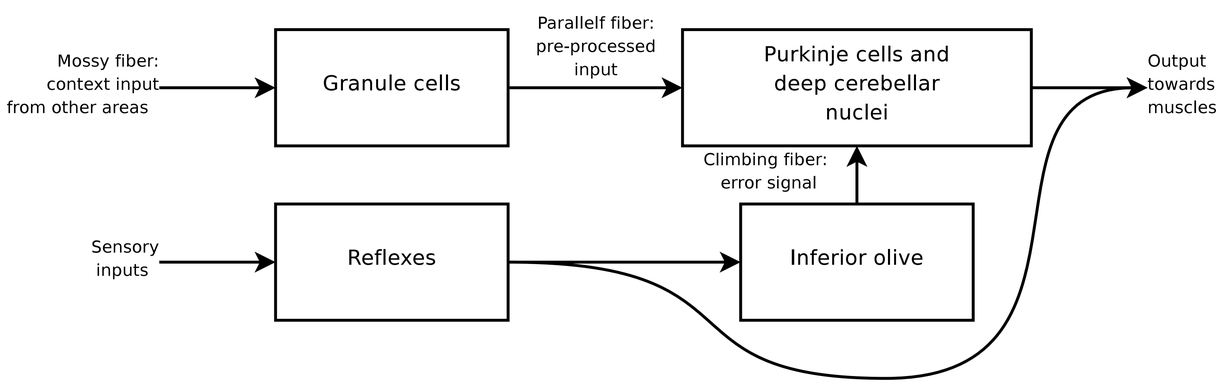
There have been two main branches of cerebellum research. On the one hand, more and more accurate biological models have been developed (e.g., [2]). On the other hand, simple functional models that exhibit the main features of the cerebellar algorithm have been developed to control physical systems (e.g., [3, 4, 5]). With suitably chosen reflexes and learning coefficients, a controller using the cerebellar algorithm learns to, for instance, keep a dynamically balanced wheeled robot upright[6].

The Model

The learning algorithm implemented by the cerebellum is simple but powerful: if a reflex is triggered in response to an event, the system will associate the action of the reflex with the states that preceded the event. The next time a similar state is observed, the system will anticipate the reflex by performing the reflex action beforehand.

Figure 1 shows a simplified model of cerebellum and the even more simplified mathematical formulation we use for our control application. The crucial idea is to learn correlations between events that happened just before a disturbance by keeping an eligibility trace of the inputs and adapting the weights according to it and the reflex.

a)



b)

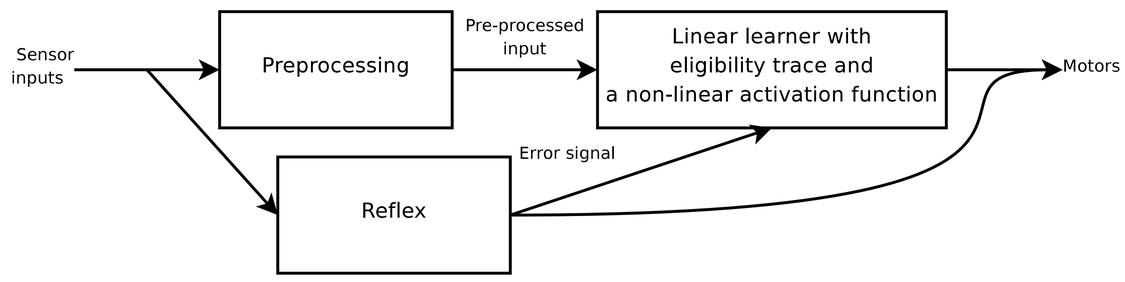


Figure 1. a) A simplified model of the cerebellum. b) The mathematical model used in our simulations.

The Simulation

We look at the case of an articulated, compliant multi-jointed robotic arm with delay. This is a very difficult system to control, because the dynamics of the different degrees of freedom are connected mechanically: moving one joint causes a force to be exerted on the other joints, which can easily lead to unstable and chaotic states. The cerebellar controller is able to learn to control this system by compensating for the position and motion of other joints proactively.

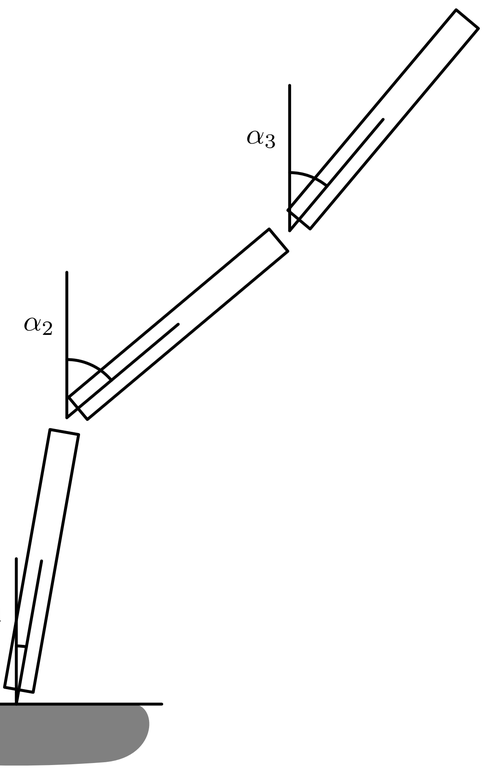


Figure 2. The parameterization of the robot. The axes of the three rotational joints are parallel.

Results

The cerebellum learns to balance the arm steadily, despite the sensory delay and the interaction between the degrees of freedom. From inspection of the learned weights it is obvious that the system learns to compensate, for example, the upcoming corrective motion by by also applying power to and , even though the reflex for each joint take into account only the position and velocity of the joint itself.

In Figure 3, the two bar graphs in the middle show the instantaneous reflex values (the upper gray bars), and the instantaneous forces outputted by the cerebellar controller (the lower red bars). The reflex for each joint depends only on the angle and angular velocity of that joint. The topmost joint would be forced right because it is momentarily traveling rapidly towards the left.

Using the reflexes directly as the action would result in instability, since pushing the lowest joint left would cause the highest joint to go even more to the right and slow down too much and this would eventually lead to vibration. The cerebellum predicts the effect of the lowest joint on the upper joints and adjusts its output signal appropriately.

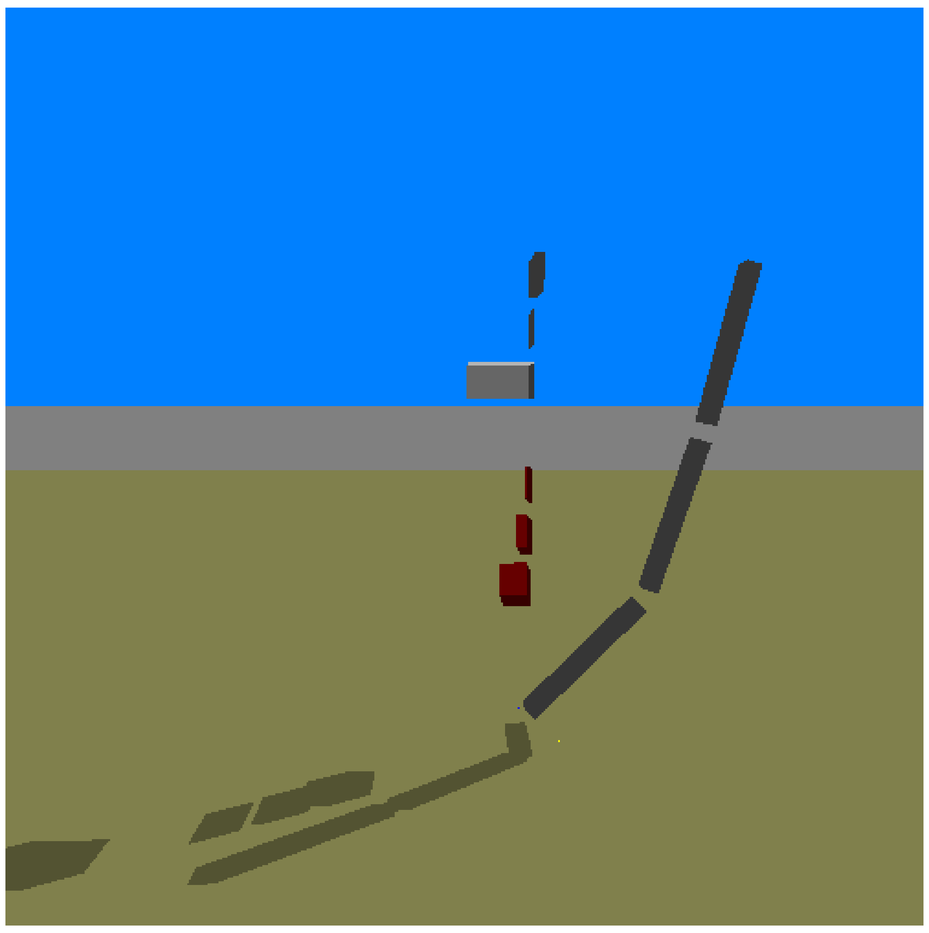


Figure 3. A screenshot of the simulation running in a physics simulator.

References

[1] M. Ito. (2002), Annals of the New York Academy of Sciences **978**:273–288

[2] D. Bullock, J.C. Fiala, and S. Grossberg (1994), Neural Networks **7**(6–7):1101–1114

[3] M. Kawato, K. Furukawa, and R. Suzuki (1987), Biol.Cybernetics **57**:169–185

[4] R. Smith (1998), Ph.D. thesis Intelligent Motion Control with an Artificial Cerebellum, Univ. of Auckland, New Zealand

[5] A.G. Barto, A.H. Fagg, N. Sitkoff, and J.C. Houk (1999), Neural Computation **11**(3):565–594

[6] H. Valpola (2006), In Proceedings of the Ninth Scandinavian Conference on Artificial Intelligence, Espoo, Finland, 2006, 135–142