Neural Control for Locomotion of Walking Machines

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The basic locomotion and rhythm of stepping in walking animals like cockroaches mostly relies on a central pattern generator (CPG) [1], while their peripheral sensors are used to control walking behaviors [2]. By contrast, in stick insects, sensory feedback serving as reflexive mechanism plays a critical role in shaping the motor pattern for adaptivity and robustness of walking gaits [2]. Inspired by the principles of biological locomotion control, two different types of neural mechanism for locomotion control of walking machines are presented. One is called modular reactive neural control and the other is adaptive reflex neural control.

Modular reactive neural control [3, 4] consists of three subordinate networks or modules (gray boxes in Fig. 1B): a neural oscillator network, two velocity regulating networks (VRNs), and a phase switching network (PSN). A simple neural oscillator network serves as a central pattern generator [1] (CPG) producing the basic rhythmic leg movements and motor coordination of the six-legged walking machine AMOS-WD06 (see Figs. 1A and C). Other modules, like the velocity regulating and the phase switching networks, enable the machines to perform omni-directional walking as well as versatile reactive behaviors[1], like self protective reflex [4], obstacle avoidance [3, 4, 5], phototaxis [5], wind-evoked escape, and acoustic startle response. These behaviors are generated in a sensori-motor loop with respect to appropriate sensor inputs, to which a neural preprocessing is applied. The presented neuromodules are small so that their structure-function relationship can be analyzed. The complete controller is general in the sense that it can be easily adapted to different types of even-legged walking machines without changing its internal structure and parameters [3, 4].

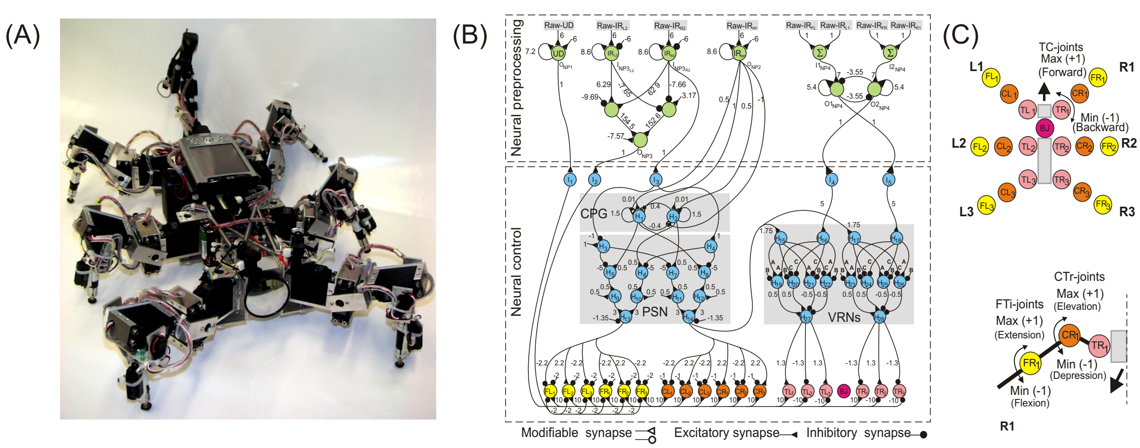

Figure 1: (A) The physical six-legged walking machine AMOS-WD06. (B) Modular reactive neural control. Green neurons describe the neurons of preprocessing networks, blue neurons are the input and hidden neurons of the neural locomotion control network, and yellow, orange and pink neurons depict motor neurons. (C) Upper: the location of the motor neurons on the AMOS-WD06 and the forward (+) and backward (−) movements of the thoraco-coxal (TC-) joint. Lower: the movements of the coxa-trochanteral (CTr-) joint and the femur-tibia (FTi-) joint of the right front leg (R1) with the remaining legs of the machine performing the same (front view).

Adaptive reflex neural control [6] is based on reflex mechanisms. It consists of two neural modules (see Fig. 2B). One is for leg control and the other is for body control. Leg control has three local loops. A joint control loop arises from angle sensors (S) at each joint influencing its target motor neuron. An inter-joint control loop is achieved from stretch receptor sensors (A) at the hip. A leg control loop comes from ground contact sensor (G) driving the motor (N). Body

[1]see [3, 4, 5] for details and more demonstration at http://www.nld.ds.mpg.de/∼poramate/AMOSWD06.html.

control (UBC) represents a long-loop reflex and its sensor (AS) is involved in controlling plasticity within the whole network. In our learning mechanism (see dashed frame in Fig. 2B and also [7] for details), it consists of six learner neurons changing activation parameters of their target neurons. The modification of those parameters is controlled by an early input (IR) and a later input (AS). This adaptive control enables RunBot (see Fig. 2A) to perform fast dynamic walking and autonomously learn to adapt its locomotion to different terrains[2].

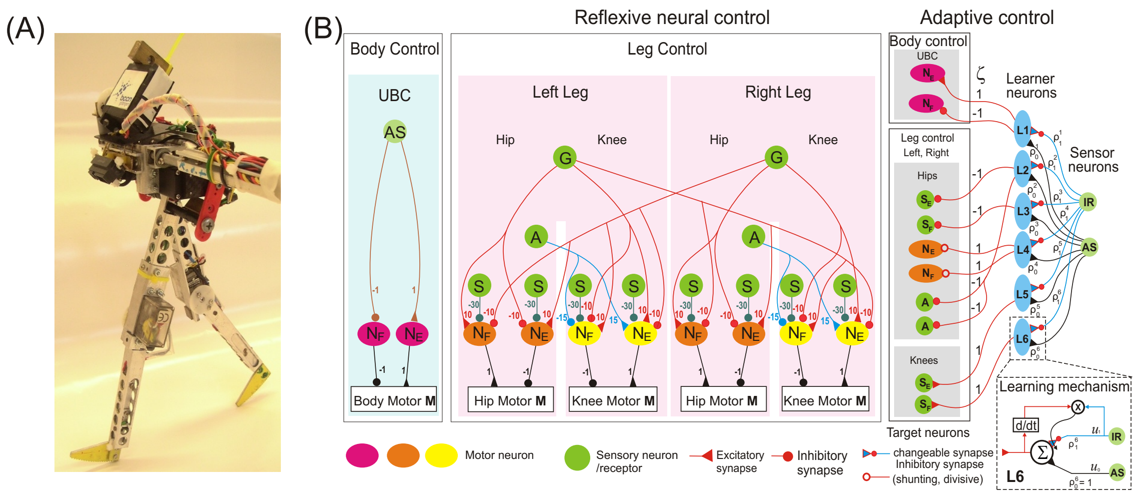

Figure 2: (A) The physical two-legged walking machine RunBot. (B) Adaptive reflex neural control.

This study shows that the proposed neural control can be a powerful technique to better understand and solve sensori-motor coordination problems of many degrees-of-freedom systems like sensor-driven walking machines.

References

[1] F. Delcomyn, Walking robots and the central and peripheral control of locomotion in insects, *Autonomous Robots* 7:259-270, 1999.

[2] R.E. Ritzmann, A. Bueschges, Insect walking: From reduced preparations to natural terrain, in: G. North, R.J. Greenspan (Eds.), *Invertebrate Neurobiology*, Cold Spring Harbor Laboratory Press, 2007.

[3] P. Manoonpong, Neural preprocessing and control of reactive walking machines: Towards versatile artificial perception-action systems, *Cognitive Technologies*, Springer-Verlag, 2007.

[4] P. Manoonpong, F. Pasemann, F. Wörgötter, Sensor-driven neural control for omnidirectional locomotion and versatile reactive behaviors of walking machines, *Robotics and Autonomous Systems* 56(3): 265–288, 2008.

[5] P. Manoonpong, F. Pasemann, F. Wörgötter, Reactive neural control for phototaxis and obstacle avoidance behavior of walking machines, *International Journal of Mechanical Systems Science and Engineering* 1(3): 172–177, 2007.

[6] P. Manoonpong, T. Geng, T. Kulvicius, P. Bernd, F. Wörgötter, Adaptive, fast walking in a biped robot under neuronal control and learning, *PLoS Computational Biology* 3(7):e134, 2007.

[7] P. Bernd, F. Wörgötter, Isotropic sequence order learning in a closed loop behavioural system, *Roy Soc Phil Trans Mathematical Physical Engineer Sci* 361:2225-2244, 2003.

[2] see demonstration at http://www.nld.ds.mpg.de/∼poramate/Runbot.html.