Motor learning and body size within an insect brain computational model

Paolo Arena[a,b], Luca Patané[a] and R. Strauss[c]

[a]Dipartimento di Ingegneria Elettrica, Elettronica e Informatica,
University of Catania, Italy
[b]National Institute of Biostructures and Biosystems (INBB), Viale delle Medaglie d'Oro 305,
00136 Rome, Italy
[c]Institut für Zoologie III (Neurobiologie), University of Mainz, Germany
{parena, lpatane}@dieei.unict.it

1 Extended abstract

Research interest in studying insects has being recently received a growing interest for many reasons among which the impressive adaptation and learning capabilities shown while solving a multitude of different tasks [1–3]. Nowadays modeling insect brains is also an important source of inspiration to develop learning architectures and control algorithms for applications on autonomous walking robots.

Within the insect brain two important neuropiles received a lot of attention: the mushroom bodies (MBs) and the central complex (CX). Recent research activities considered the MBs as a unique architecture where different behavioral functions can be found. MBs are well known in bees and flies for their role in performing associative learning and memory in odor conditioning experiments [4]. They are also involved in the processing of multiple sensory modalities among which visual tasks [3], different forms of learning in choice behavior [5] and, as recently introduced, also in motor learning [6]. The CX is mainly considered as a center for the initiation of behaviors; it is responsible for visual navigation, spatial memory and visual feature extraction [7, 8]

To unravel the neural structures involved in these learning processes, among the different insect species we focalized our attention on the *Drosophila melanogaster* where, through genetic tools, it is possible to inhibit the activity in specific neural sites creating mutant flies, at the aim to better understand which neural circuitries are responsible for the different behaviors shown.

An important capability needed by animals to interact with the environment is related to the embodiment: how an animal decisions depend from the shape of its body and which are the mechanisms involved, are important questions that we started to unraveling in our works. Looking in this direction, the concept of peripersonal space is an interesting research topics for psychologists, neurobiologists and also for robotic applications. A living being can learn the representation of its own body to take the correct behavioral decision when interacting with the world. Even simple insects like *Drosophila* can learn to adapt their behaviors depending on their body size. This important information used to take decisions is acquired by flies using multisensory integration strategies: they need to connect visual input with tactile experience.

It seems that the formation of the own body size knowledge needs that the fly is able to walk and generate parallax motion. The average step size, which is proportional to the leg length and therefore to the body size, creates an average parallax motion that allows to evaluate the distance from objects present in the environment in relation with the fly body, creating a form of reachable space around the fly.

Following this evidence a computational model based on spiking neurons and threshold adaptation learning mechanisms was developed and tested both in a simulated legged robot and in a real roving platform [9]. The results demonstrate the capability of the system to learn how to shape its behaviors depending on its body size. Interesting results were also provided by artificially altering the visual perception of the robot either by emphasizing or compensating the parallax, by moving the visual target. The learning procedure, initially applied to a targeting task, can be extended to other tasks like gap climbing and obstacle overcoming. This process leads the agent to reach a decision on the affordability of a given task. Once taken this decision the agent undertakes a series of attempts leading to improve the animal capabilities through motor learning. Motor learning is needed to survive in changing environments. It can be defined as the process to acquire precise, coordinated movements needed to fulfill a task. In performing motor learning agents, apply operant strategies in which a movement is made and sensory feedback is used to evaluate its accuracy.

On the basis of the known elements acquired through behavioral experiments in a gap climbing scenario [10], we proposed a new architecture for motor learning inspired by specific structures of the insect brain involved in these processes [11]. The proposed model is a nonlinear control architecture based on spiking neurons. According to the actual neurobiological knowledge, the centers involved in such learning mechanisms are the Mushroom Bodies. They are modeled as nonlinear recurrent spiking neural networks with novel characteristics able to memorize time evolution of key parameters of the neural motor controller, so as to learn motor primitives which enable the structure to efficiently acquire new motor skills. Experimental results on a simulated hexapod robot mimicking the structure of the *Drosophila melanogaster* in a dynamic simulation environment were performed. A block scheme illustrating the key elements of the insect brain architecture able to show, among other capabilities [12], both body size and motor learning, is reported in Fig. 1 where the role of MBs and CX is depicted. The obtained results show interesting cues to be further assessed with improved experimental campaigns on insects and their mutants.

Acknowledgments. The authors acknowledge the support of the European Commission under the project FP7-ICT-2009-6 270182 EMICAB.

References

1. M. Menzel, R.; Giurfa, “Dimensions of cognitive capacity in an insect, the honeybee,” *Behav. Cogn. Neurosci. Rev.*, vol. 5, pp. 24–40, 2006.
2. N. J. Chittka L., “Are bigger brains better?” *Current Biology*, vol. 19, p. R995R1008, 2009.
3. G. Liu, H. Seiler, A. Wen, T. Zars, K. Ito, R. Wolf, M. Heisenberg, and L. Liu, “Distinct memory traces for two visual features in the *Drosophila* brain,” *Nature*, vol. 439, pp. 551–556, 2006.

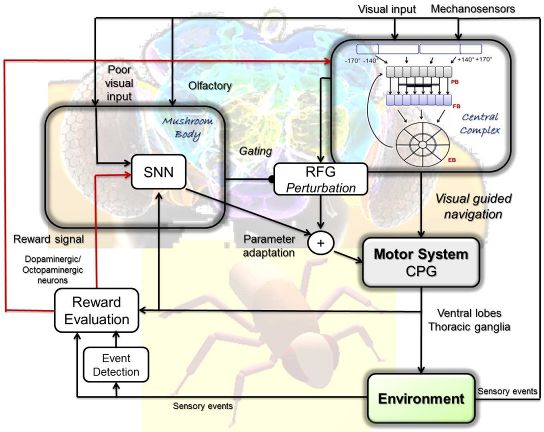

Fig. 1. Block scheme of the key elements of the insect brain involved in the body size and motor learning processes. The Mushroom Bodies and the Central Complex receive inputs from the environment including the internally generated rewarding signals. The motor system where a Central Pattern Generator has been implemented, receives the control commands from the CX for visually guided navigation and the parameter adaptation from MBs to improve the basic behaviors through motor learning. Information related to the body size of the system is acquired using the parallax motion through the CX.

4. X. Liu and R. Davis, "Insect olfactory memory in time and space," *Curr. Opin. Neurobiol.*, vol. 6, pp. 679–685, 2006.
5. S. Tang and A. Guo, "Choice behavior of drosophila facing contradictory visual cues," *Science*, vol. 294, pp. 1543–1547, 2001.
6. S. Pick and R. Strauss, "Goal-driven behavioral adaptations in gap-climbing drosophila." *Curr. Biol.*, vol. 15, pp. 1473–8, 2005.
7. M. Mronz and R. Strauss, "Visual motion integration controls attractiveness of objects in walking flies and a mobile robot," in *International Conference on Intelligent Robots and Systems*, Nice, France, 2008, pp. 3559–3564.
8. P. Arena, C. Berg, L. Patané, R. Strauss, and P. Termini, "An insect brain computational model inspired by drosophila melanogaster: architecture description," in *WCCI 2010 IEEE World Congress on Computational Intelligence*, Barcelona, Spain, 2010, pp. 831–837.
9. P. Arena, G. D. Mauro, T. Krause, L. Patané, and R. Strauss, "A spiking network for body size learning inspired by the fruit fly," in *Proceedings of International Joint Conference on Neural Networks*, Dallas, TX, 2013, pp. 1251–1257.
10. T. Triphan, B. Poeck, K. Neuser, and R. Strauss, "Visual targeting of motor actions in climbing *Drosophila*." *Curr. Biol.*, vol. 20(7), pp. 663–668, 2010.
11. P. Arena, S. Caccamo, L. Patané, and R. Strauss, "A computational model for motor learning in insects," in *Proceedings of International Joint Conference on Neural Networks*, Dallas, TX, 2013, pp. 1349–1356.
12. P. Arena and L. P. (Eds.), *Spatial Temporal Patterns for Action-Oriented Perception in Roving Robots II: an insect brain computational model*. Springer, Series: Cognitive Systems Monographs, Vol. 21, 2014.