How to Harness the Dynamics of a Soft Body

Timing-Based Control of a Simulated Octopus Arm via Recurrent Neural Networks

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Controlling a Soft Body: Learning from Octopus

An octopus has hyper-redundant limbs with a virtually infinite number of degrees of freedoms (DOFs), and its movements are significantly sophisticated [1]. If we can understand how to deal with soft bodies of this kind, it is expected that we will achieve manipulation skills that are far beyond what is currently possible.

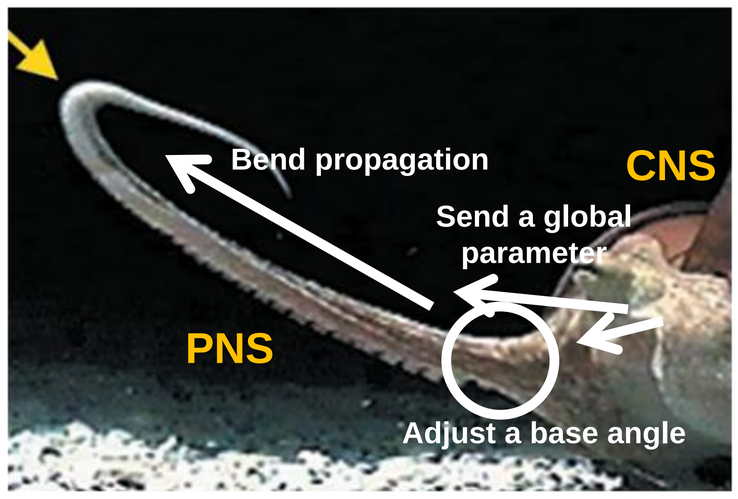


Figure 1. An octopus uses a bend propagation during its reaching behavior [2].

Importance of "Timing"

In a real octopus, it is well known that simplification strategies have evolved to reduce the number of control parameters in the movement of its flexible arms. That is, the functionality is divided between the central nervous system (CNS) and the peripheral nervous system (PNS) [2] [3].

◆**The CNS only sends an initiation command to the PNS.**

The CNS does not have to control the movement of the muscles one by one and the PNS mainly drives the behavior.

◆**The coordination between the CNS and the PNS.**

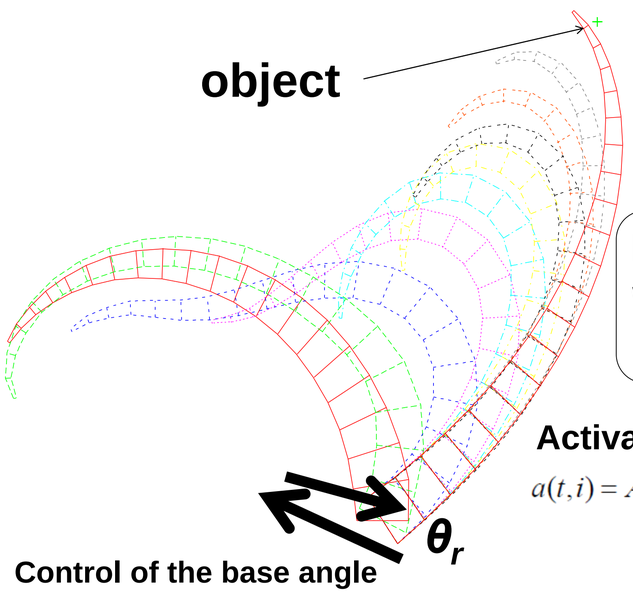
How can the CNS recognize when to apply the command to the PNS?

We need to consider an additional important factor in the control, which is "timing."

Timing-Based Control via Recurrent Neural Network

Control Architecture: The control architecture is based on a recurrent neural network (RNN), in combination with a feed forward network (FFN). The main body of the RNN controls the angle of the arm base and the timing to send a signal to the low-level control (PNS). The accompanying network decides the power of the signal and the angle hat is required to achieve the reaching behavior.

Task and training of the network: In order to determine the performance of the networks, we established the reaching tasks by using a simulated octopus arm. As revealed in octopus biology, the octopus starts to create a bend on the dorsal side of its arm and, through the bend propagation, its arm approaches the object from the ventral side. The important point here is the time it takes for the bend to form. Our aim is to autonomously control the time lag in the network. In order to achieve the reaching behavior toward the object, the networks are required to exploit the physical dynamics of the arm. For the learning of the networks we applied an incremental learning strategy. Unlike the conventional supervised learning case, we do not predefine the learning sets, but rather collect the learning sets by actually running the arm.



RNN should learn when to apply the initiation command!

Activation function

$$a(t,i) = AC_a \frac{1}{2}\left\{1+\tanh\left[\beta\left(\frac{t}{\tau}-i+i_0\right)\right]\right\}$$

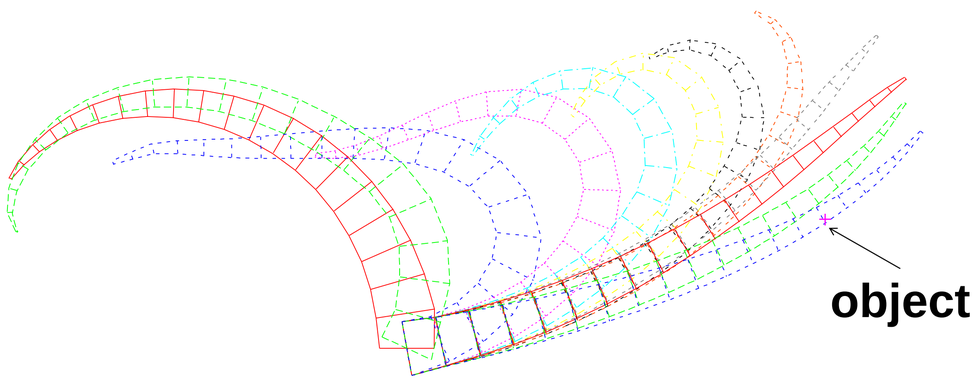


Figure 2. Examples of the arm dynamics during the reaching behavior controlled by the RNN.

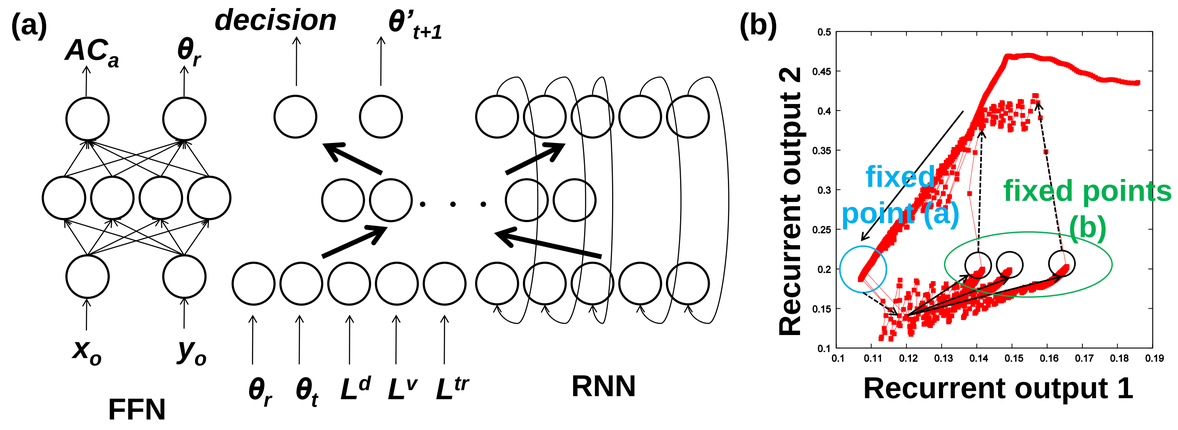


Figure 3. (a) Dual network controlling the timing for reaching behavior. (b) Internal dynamics of the RNN when controlling the timing.

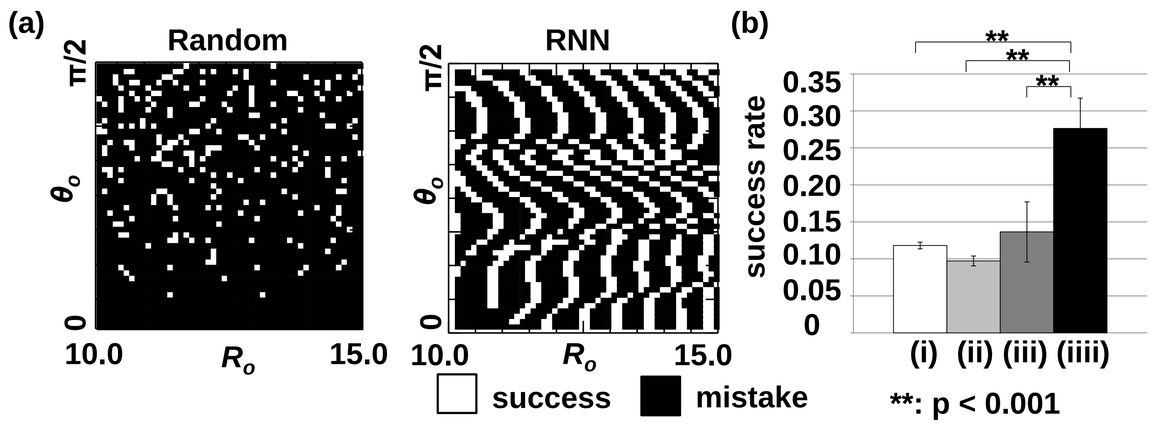


Figure 4. (a) Results showing the performance of the reaching behavior controlled by the RNN (right), compared with the random control (left). (b) RNN achieved significantly higher performance than the several control conditions.

Conclusion

Usually, to deal with a soft body, we tend to focus on the control that straightforwardly regulates its high DOFs one by one and moment by moment; this approach seems to ignore and restrict the natural dynamics that the soft body intrinsically has. In our approach we exploit its body dynamics positively [4]. By introducing the timing-based control, we demonstrated and showed that it is possible to release and harness the body dynamics that are hidden underneath the control.

Acknowledgments

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