Novel type of neuromorphic control system using stochastic resonance

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Stochastic resonance (SR) is a phenomenon in which noise enhances the response of a nonlinear system to a weak signal. It has been identified in various physical system and biological system. Noise is intuitively interfering factor, but it can be used to provide a functional benefit of signal coherency amplification in the stochastic resonant systems. Recent studies suggest the potential technological application of SR, such as for sensors to detect weak signal, image reproduction in visual perception, and nonlinear memory storages, and aim for the common utilization of this phenomenon in the engineering field. Although it is important to develop SR for common use, a general scheme for making functional and integrated systems based on SR has yet to be investigated. In order to broaden the use of SR, we explore an integration scheme of SR element. As informative examples, given that the neuron is an SR element, nervous systems could be considered one integrated system comprising SR elements. Hence, we focused on the central pattern generator (CPG), which is a neural oscillator of vertebrate spinal cord. Inspiring the CPG system, we developed a control system of locomotion robot by assembling artificial neuron (SR-neuron) devices.

In this talk, I introduced a neuromorphic control system constructed of the ring oscillator of the SR-neuron devices. In order to realize the control system, I proposed a neuron model which was easy to implement in an electronic circuit system and possible to handles the time domain dynamics for neuron's action and SR. The SR-neuron device with operational amplifier circuits was examined for the response of noise input, confirming the SR behavior. The SR-neuron devices were, furthermore, investigated for cooperative dynamics in the recurrent ring connection. The recurrent ring showed quasi-periodic oscillation with some fluctuation by only adding noise. The oscillation frequency depended on noise amplitude and coupling strength among SR-neuron devices; large amplitude noise and small coupling strength induced high frequency oscillation. The oscillation coherency was enhanced at a noise amplitude, indicating that the ring system also show the SR property. It means that the ring oscillator effectively uses noise like biological systems.

I demonstrated the biomimetic control of phototaxis behavior (e.g. like that insects gather to light) using a locomotion robot. This control was achieved by the competitive action of the oscillation signals arising from the neuron firings of the SR-neuron devices without using computer and program (Turing machine mechanism is absent anywhere). It is considered that the system is truly operating by the neuromorphic principle. Finally, I proposed three criteria for which neuromorphic systems have to show: self-similarity, spontaneous-fluctuation, and stochastic resonance.