Design methodologies for Central Pattern Generators: Toward “intelligent” locomotion in robots

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Introduction

The control of locomotion in legged robot and especially in humanoid robots is the first step to embodied cognition and intelligence. This is the step that allows the robot to interact and to discover its environment. However, it is not straightforward how to design good controllers so that the robot can move in unpredictable environment. Unlike animals, robots are not really able to adapt to a changing environment. It is known from biology that the coordination of the limbs during periodic movements is done in the spine of animals [1,2]. The involved neural circuits are called Central Pattern Generators (CPGs). These are self-contained distributed neural networks that can generate all the complex signals that control the coordination of the muscles. Taking inspiration from biology led to very successful locomotion controllers [3-6]. However, the design of such CPGs remains really difficult and very few methodologies are available to construct such systems [4,5], most of the time they need extensive optimization procedures and fine-tuning. The goal of our work is to provide generic design methodologies to construct CPGs, by using the dynamical systems approach. We show through the design of a controller for a crawling baby humanoid robot, which will be used in the RobotCUB project [7], how we can use mathematical tools from the dynamical systems framework to design CPGs.

Crawling Humanoid Robots

As part of the RobotCUB project, our controller is built in order to allow the robot to explore its environment by moving on its arms and legs (i.e. crawling). The CPG is made of originally coupled oscillators. These oscillators are spring-like systems that are bounded in energy and which have a nonlinear spring constant. They exhibit limit cycle behaviour and we can control independently the duration of the ascending and descending phases of the oscillations (i.e. the duration of the swing and stance phases). By using group-theoretic arguments [8] we can easily infer a minimal network that can generate the desired spatio-temporal pattern. With this methodology, our controller comes with generic properties which are important for robotics. The system is stable against perturbations, which will allow the integration of sensory feedback and a tight coupling with the environment. We can easily modulate the pattern in frequency and amplitude and moreover the duration of both the swing (when the limb lifts off the ground) and stance (when the limb touches the ground) phases can be controlled independently. With this simple controller we show that we are able to generate trajectories that correspond to the ones of real crawling babies and we successfully apply this to the control of the simulated iCub humanoid (which is currently under construction).

Conclusion

Although our design is specific to the control of crawling in a humanoid robot, our approach is quite general and could be successfully applied to the control of other kinds of legged robots. The oscillator we use in association with the symmetry arguments [8] give a simple and generic method to construct a CPG for any kinds of gait for legged robot. The next step would be to study the coupling of the CPG with the environment in order to make it adaptive to changes in the environment. The structure of our controller should allow such a coupling, as was already shown in [6] and more recently in [9] where they were able to adapt parameters of the oscillators to the body dynamics.

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