Bipedal Locomotion Control with Rhythmic Neural Circuits

J. Nassour[1,3], P. Hénaff[2], F. B. Ouezdou[1], and G. Cheng[3]

[1] Versailles Saint Quentin University - France
[2] University of Cergy Pontoise, ENSEA, CNRS-F95000 Cergy Pontoise
[3] Institute for Cognitive Systems, Technical University Munich
{*ouezdou, nassour*}*@lisv.uvsq.fr, patrick.henaff@u-cergy.fr, gordon@tum.de*

Abstract. ***This paper present a biologically inspired rhythmic neural circuitries that enable robustness bipedal locomotion control, introduction of phase resetting yield to perturbations; and the introduction of a patterns switching mechanism allows behavior adaptions that enable the handling of greater perturbational forces.***

1 Introduction

Research in robot locomotion can be separated into few groups. The dominated research is based on a high level modeling approach, like ZMP control that incorporate inverse kinematics techniques, which suffers from the problem of high dimensionality, delays, and the requirement of perfect knowledge of the robot and environment. Taken inspiration from neuroscience, with the attention on biological inspired locomotion for robot control [1]. These controllers do not require perfect knowledge of the robot's dynamics as with classical strategies and have shown great promise in terms of robustness, simplicity and adaptivity. Biological inspired locomotion controllers are based on simple circuits that are built from sensor-neurons, motor neurons, and inter-neurons [2] [3]. Neurophysiological studies associate rhythmic movements with the oscillation activity of a particular type of neurons, called neural oscillators [4] [5]. These oscillators can produce rhythmic activity without sensory inputs and even without any central inputs. But the sensory information is indispensable for walking because it allows shaping of the rhythmic patterns in order to interact with the environment [6]. However, sensory information is mainly used to adapt the controller in the event of changes and perturbations. Neurophysiologists have shown that biological controllers like Central Pattern Generators (CPG) have adaptation properties due to neural plasticity mechanism [4] [7]. With inspiration from neurobiology, Ijspeert et al. proposed different models for rhythmic movements control [3]. The neural reflexive walking controller, proposed by F. Wörgötter is one of the few that have been tested on a real bipedal robot [2]. Our work aims to produce a robust biological inspired neural controller for biped walking, based on CPG with a rhythmic neuron proposed by Rowat and Selverston [5]. We show therefore how to adapt against an external perturbation force by phase resetting or by behavior adapting. This paper is organized as following. Section 2 presents the principles of the neural controller based on the model of rhythmic neurons, which is able to generate CPG-like patterns. The three layers of the CPG used in bipedal control are presented. A coupling circuitry for walking is proposed. Next, two approaches to deal with for external perturbation is presented. The last section gives a conclusion and details of further developments.

2 Bio-Inspired Neural Controller for Locomotion

Studies of rhythmic movement in the animal show that local circuits in the spinal cord are able to control the timing and coordination of complex motion patterns [8]. The locomotion and rhythmic movements in mammals are organized by oscillatory spinal cord circuits called CPGs. Experimental studies show that the rhythmic patterns in cat limbs can be generated in the absence of descending control from higher centers and sensory feedback [4]. Each joint appears to have its own CPG, which can be coupled to the CPG of another joint in order to achieve complex movements such as walking, running, swimming, etc. It has been hypothesised that these CPGs, controlling such behaviors in animals? locomotion can be responsible for rhythmic movements in human locomotion.

In order to achieve a rhythmic movement such as walking, we have implemented a CPG model on a dynamic simulation of a biped robot fig.1(f). Fig.1(a,b,c,d) show the wiring diagrams for knee, ankle, hip, and trunk joints. Fig.1(e) show the coupling circuitry between CPGs. Each CPG can be separated into three layers: 1) Rhythm Generation neurons (RG); 2) Pattern Formation neurons (PF); and 3) MotorNeurons (MN). Sensory feedback shapes the activity of these neurons. We focused on the effect of descending control to the rhythmic neurons in order to control the behavior of these neurons when external perturbation occurs during walking.

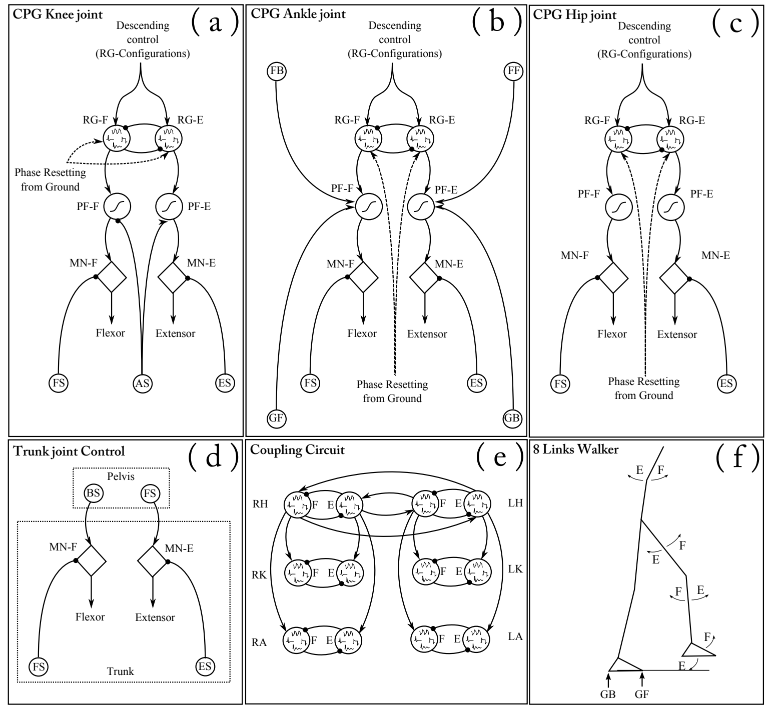

Fig. 1. Neural controller and 8-links simulated walker. (a): The Central Pattern Generator for knee joint. RG-F, PF-F, and MN-F are rhythm generator neuron, pattern formation neuron, and motor neuron for flexion, RG-E, PF-E, and MN-E are similar neurons for extension [4]. FS and ES are a flexion and extension sensor neurons from corresponding joints. AS is a hip extension sensor neuron for extension reflex [2]. (b): The Central Pattern Generator for ankle joint. FB and FF are neurons that represent the risk of fall backward or forward according to the different between the position of Centre of Mass on the ground and Centre of Pressure. GB and GF represent the forces of contacts for corresponding leg in the back and in the front of the foot, see Fig.1.(f). (c): The Central Pattern Generator for hip joint. (d): The controller for trunk joint. The objective of this controller is to keep pelvis link with the vertical. BS and BF are the sensor neurons that represent the angular position of pelvis with the vertical direction, one neuron in the back and another in the front. (e): Coupling circuits between rhythm generators in hip, knee, and ankle joints. RH indicates right hip, RK is right knee, RA is right ankle. LH, LK, and LA indicate hip, knee, and ankle for left leg. Neurons in (e) are rhythm generators neurons for hip, knee, and ankle joints for left and right legs. (f): 2D simulated walker, simulation was done in MATLAB environment. The simulated robot mass is 22 kg.

The rhythmic neurons are inspired from the model of Rowat and Selverston[5], that can generate different types of patterns, not only oscillatory ones. With different values of the modeling parameters of rhythmic neuron (σ_s, σ_f), different intrinsic behaviors can be observed on the joint controlled by such CPG: quiescence (Qui), almost an oscillator (A-Osc), oscillator (Osc), and plateau (Pl), as shown in Fig.2.

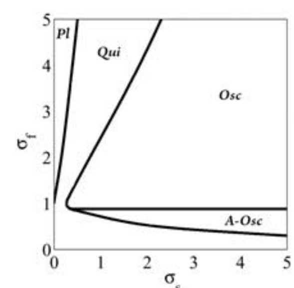

Fig. 2. Different intrinsic behaviors observed on a joint according to parameters of rhythmic neuron (σ_s, σ_f): quiescence (Qui), almost an oscillator (A-Osc), oscillator (Osc), and plateau (Pl).

3 Controller Robustness against Perturbation

Phase Resetting

Fig.3 shows the role of rhythm generator phase resetting in face of a perturbation force ($10N$) applied on the back of the simulated walker during a whole step. In the first case, walking is done without phase resetting. In the next case, walking is achieved with phase resetting of rhythm generator neurons, this gives more robustness in walking against the perturbation force. Naturally, with a larger force, this technique can not guarantee to avoid the biped robot from falling.

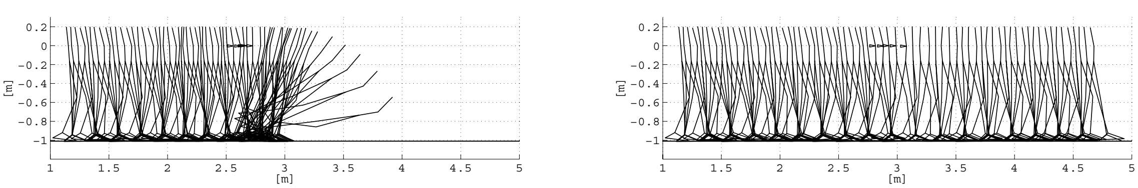

Fig. 3. Left side shows walking with oscillatory patterns without phase resetting, the simulated walker fall after a perturbation force applied on the back during whole step. Right side shows walking and resistance for perturbation with phase resetting by ground.

Behavior Adaptation

Fig.4 shows the space of patterns as a neural representation. With this neural representation, we proposed a new method to represent patterns according to its energies [10]. This allows switching easily between patterns (neurons) to adapt the behavior for a perturbation.

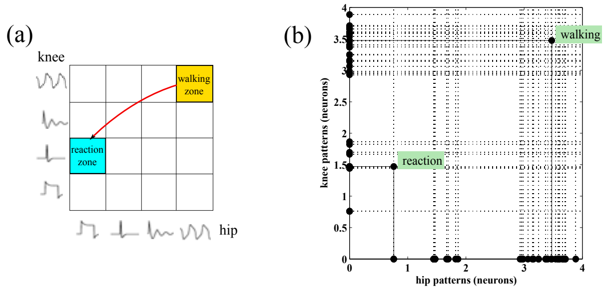

Fig. 4. The space of patterns is for hip and knee joints, with an example of switching against perturbation. (a) Patterns switch from walking by oscillatory patterns to quiescent pattern for knee and plateau for hip. (b) Neurons switch from walking zone to other neurons that represent quiescent pattern for knee and plateau for hip. Each neuron represents one pattern.

Fig.5 presents the normal walking on a flat terrain without any perturbation. Next, it illustrates the fall because of external perturbation force of $45N$ applied on the back of the robot (the walking speed is almost $0.2m/s$). It shows in the last how the biped robot reacts correctly against the external force by adapting the behavior of the rhythm generators neurons.

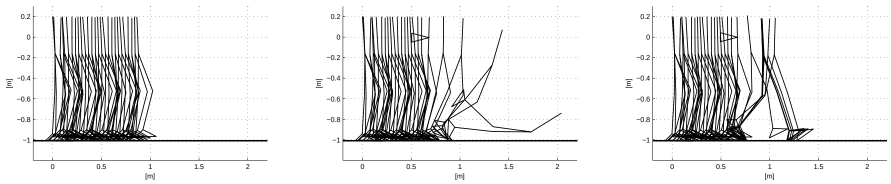

Fig. 5. Role of adaptation mechanism on the biped to avoid falling: Walking without perturbation, falling due to the perturbation, and successful walking when perturbation occurs.

4 Conclusion

In this paper, a neuro-biologically inspired controller for biped walking was presented. We showed its robustness to deal with perturbation forces applied from the back. Our methods were based on: 1) resetting the phase with ground contacts sensor; 2) we showed how the behavior in rhythm generator neurons brings adaptation to deal larger external perturbations. Our future work will address learning to switch between patterns to achieve different locomotion skills. And apply this technique on a real robot.

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