An Adaptive Neuromechanical Model for Muscle Impedance Modulations

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Motivations

Recently, an integrative view of neural circuits and mechanical components has been developed by neuroscientists and biomechanicians. This view argues that mechanical components cannot be isolated from neural circuits in the context of substantially perturbed locomotion. Besides, it is well known that neural activities modulate muscle impedance such as stiffness and damping, such modulations can be utilized for stabilization in posture and locomotion.

Cockroach Experiment

A cockroach experiment has demonstrated that

- Larger obstacles (more than three times cockroach hip height): more modulations of neural activities are detected.
- Moderate obstacles (less than three times cockroach hip height): cockroaches are able to solely rely on passive mechanical properties for rapid stabilization.

Figure 1: Blaberus discoidalis on rough terrain with a random distribution of surface heights.

Muscle impedance

Muscle impedance here is the dynamic relation between antagonistic muscles and imposed stretch. Antagonistic muscle impedance includes the stiff and damper.

Adaptive Neuromechanical Model

The adaptive neuromechanical model has a set of distributed and nested loops consisting of a minimal neural circuit and virtual muscle mechanisms as well as mechanical components.

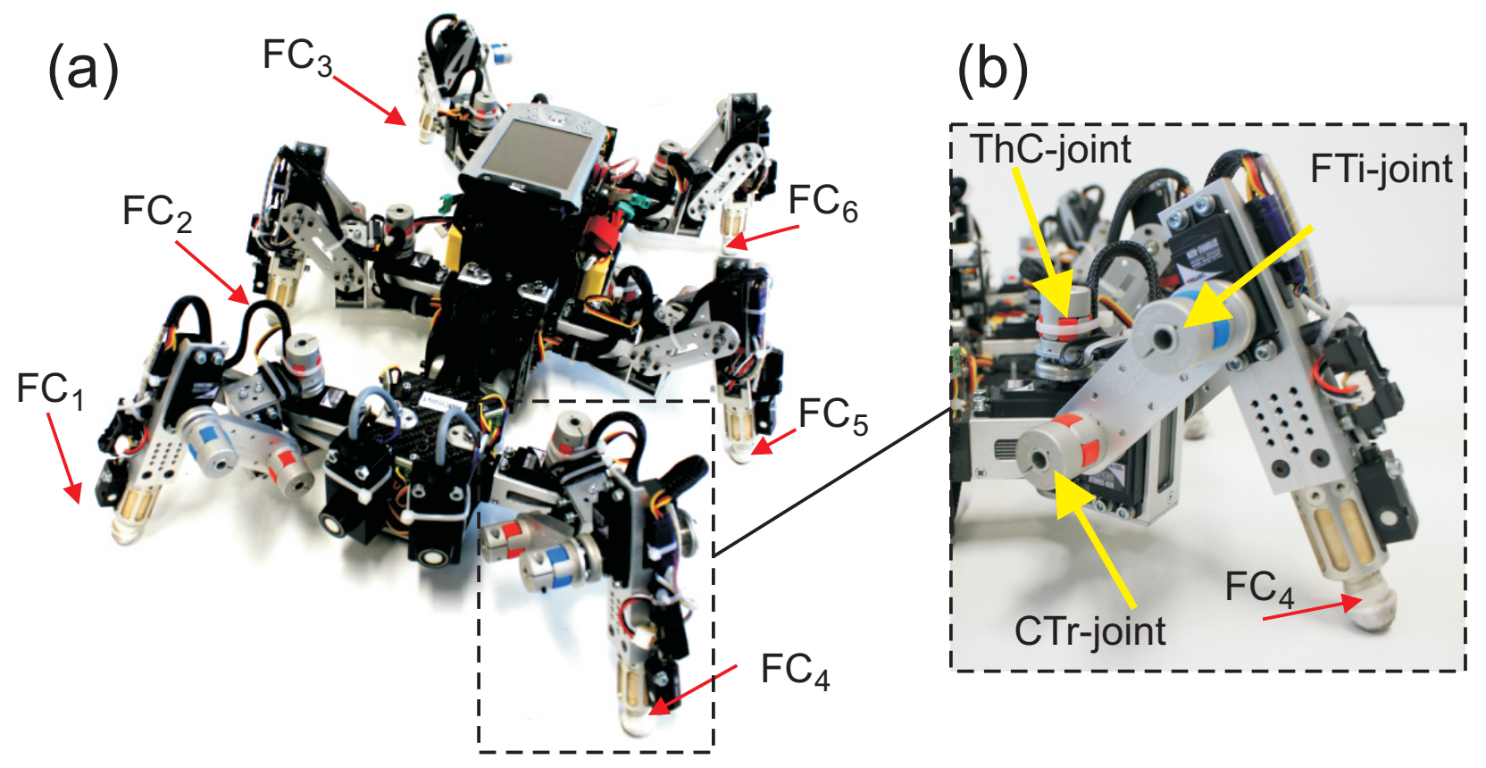


Figure 2: The six-legged walking machine AMOSII inspired by the morphology of the American cockroach, which has a foot contact sensor $FC(1,2,...,6)$ for each leg. Each leg has three joints including ThC, CTr and FTi.

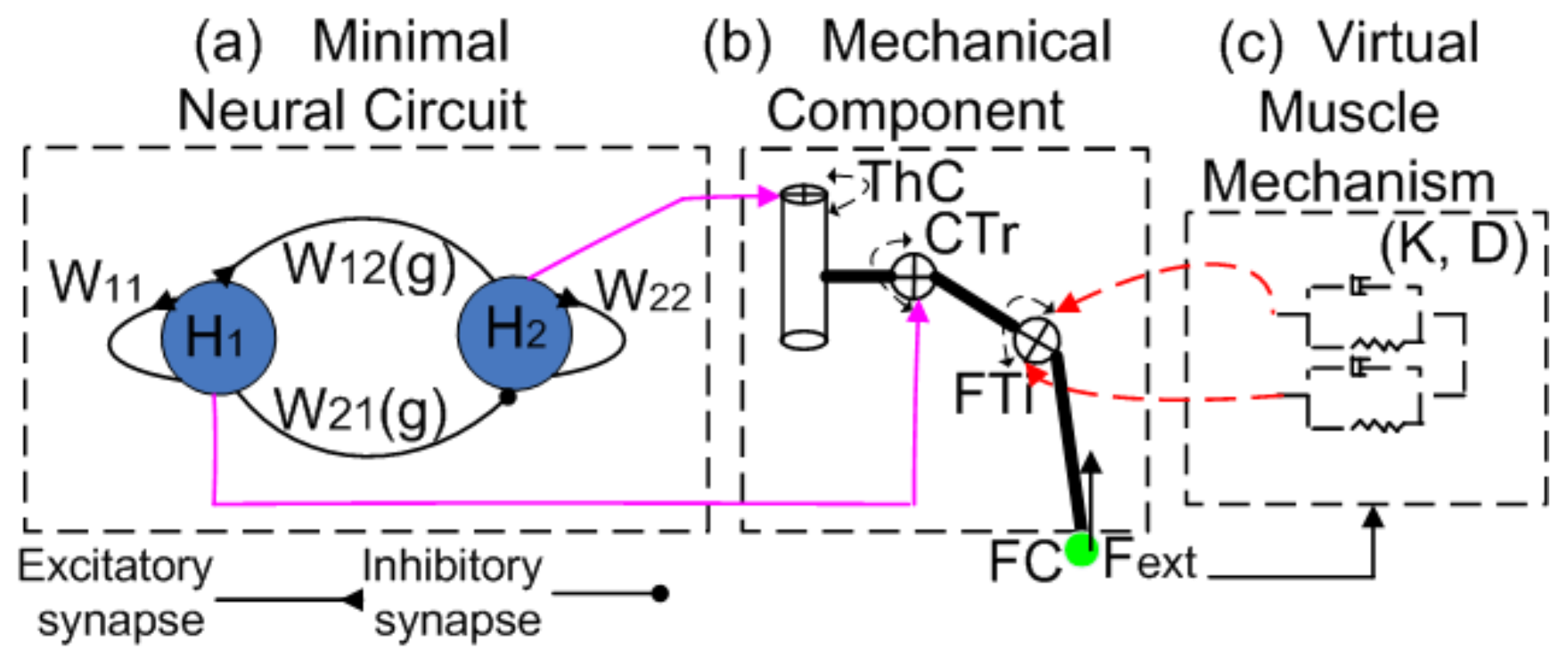


Figure 3: Adaptive Neuromechanical Model Implemented on AMOSII.

- Neural CPG circuit controlling all ThC and CTr-joints. The synaptic weights $W_{11,22}$ of the CPG circuit are set to 1.4 while others $W_{12,21}$ are regulated by a parameter g.
- Virtual muscle mechanism generating variably compliant motions of FTi joints. The mechanism is activated by a contact force signal F_{ext}.

Implementations

The Adaptive Neuromechanical Model allows us to:

- different gaits by g and variably compliant joint motions by (K, D).
- mutual entrainment between FTi joint motions driven by virtual muscles and a contact force signal F_{ext} of the mechanical system.
- yield robust motions even though contact foot sensing fails during locomotion.
- adaptation for effectively adjusting virtual muscle impedance at different speeds or gaits.

Main Results

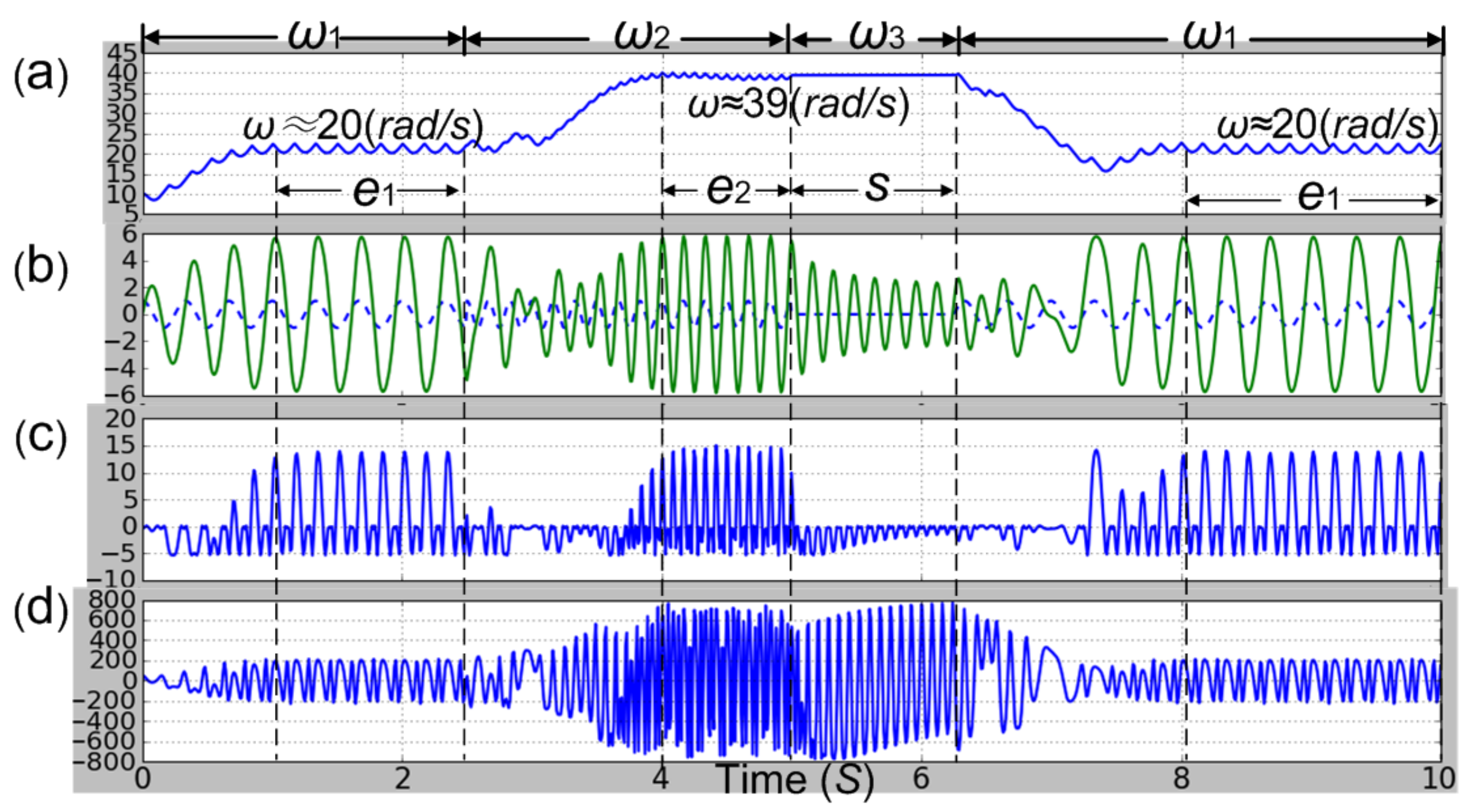
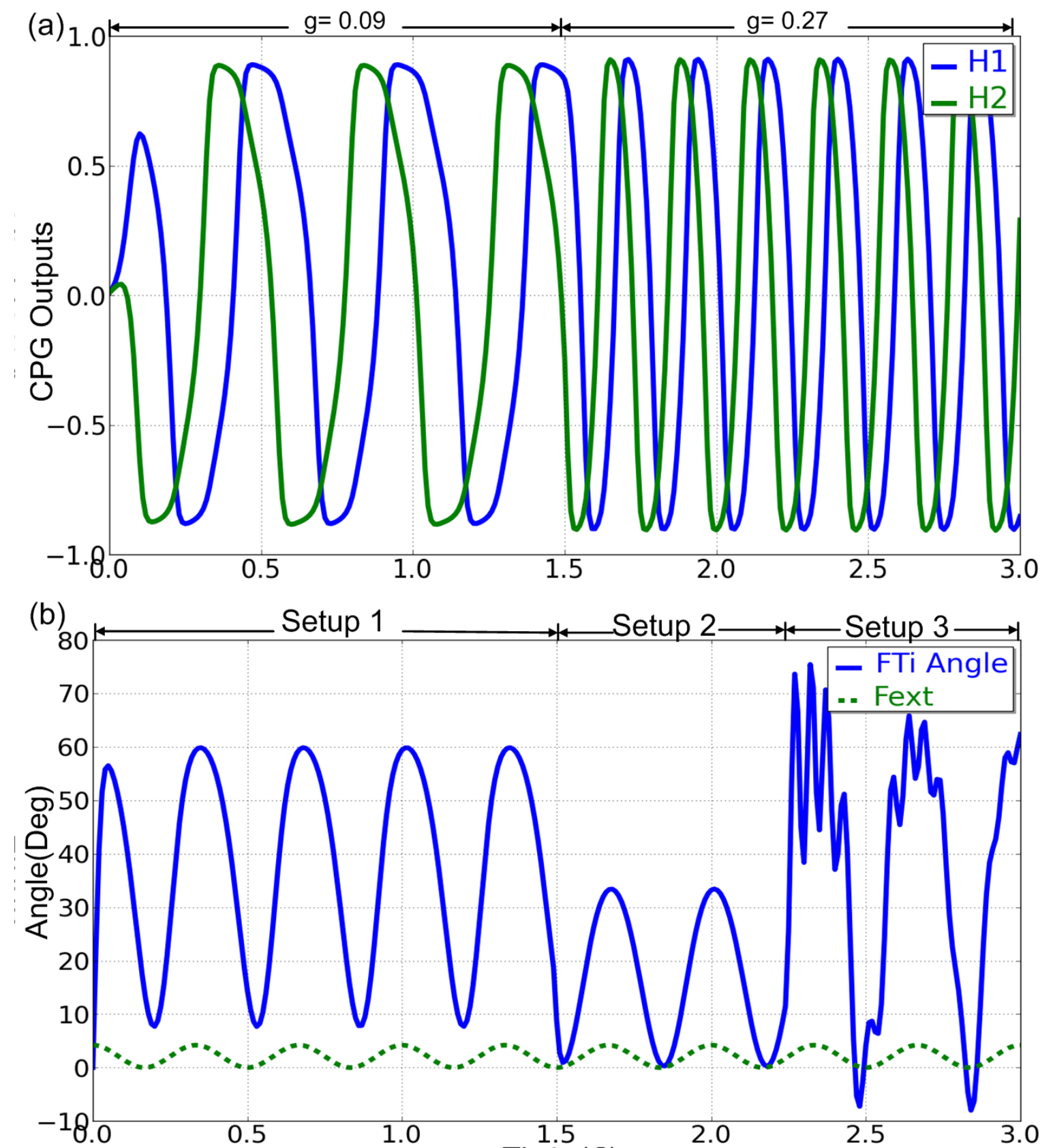


Figure 4: Virtual Muscle Impedance Modulations. Virtual muscle Impedances are actively modulated by parameters $[K, D]$. There modulations can be achieved by the entrainment between FTi joint motions driven by virtual muscles and a contact force signal F_{ext} with different angular frequencies $\omega_{1,2,3}$. (a) The angular frequency adaptation of muscle signals. (b) The entrainment between muscle(solid green) and F_{ext}(dashed blue) signals. (c) The damping parameter of muscles D (d) The stiffness parameter of muscles K. Where The angular frequency of F_{ext} set is: $\omega_1 = 6\pi(rad/s) \approx 18.85(rad/s)$, $\omega_2 = 12\pi(rad/s) \approx 37.70(rad/s)$. ω_3 means $(F_{ext} = 0)$, but virtual muscles can still produce usable signals(see the s). With angular frequencies of $F_{ext}(\omega_1$ and $\omega_2)$, virtual muscle frequencies converge to $\omega \approx 20(rad/s)$ and $\omega \approx 39(rad/s)$ respectively. After frequency adaptations, virtual muscles are entrained with the contact force signal F_{ext}, see e_1 and e_2.

Figure .5(a) The periodic output signals of CPG with different values of the parameter g (b) A pair of virtual agonist-antagonist muscles is activated by a contact force signal F_{ext}.



Conclusions and Outlook

we propose an *adaptive neuromechanical model* with active muscle impedance modulations by external feedback, which can directly vary over neural activities. This model can effectively modulate the stiffness and damping parameters of a pair of *virtual* agonist-antagonist muscles. At the same time, it can generate appropriate muscle activities entrained by external feedback. Besides, it also enables the robot to produce variably compliant motions. Note that "*virtual*" here means motions of joints imitate muscle properties without any physical passive mechanisms such as springs.

Further Information

For the details of our work:

- http://www.manoonpong.com/AMOSWD06.html.
- http://www.manoonpong.com/VirtualMuscles/SVideo1.wmv.
- http://www.manoonpong.com/VirtualMuscles/SVideo2.wmv.
- http://www.manoonpong.com/VirtualMuscles/SVideo3.wmv.

References

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