University of Waterloo

Motion Research Group

CENTRAL PATTERN GENERATOR (CPG) IN THE CONTROL OF PERIODIC ELBOW FLEXION/EXTENSION

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***ABSTRACT**: We have developed a mathematical framework that enables us to study the role of the Central Pattern Generator (CPG) in human motor control. In this model, a CPG controls the periodic motion of a forearm at different frequencies.*

INTRODUCTION

The redundantly actuated limbs in humans and animals are efficiently controlled by their Central Nervous System (CNS). The mechanisms employed by the CNS for limb control is still an open question. Strong evidence suggests that the limb control is mostly managed by Central Pattern Generators (CPGs), special neural circuits within the spinal cord, while cortical activities are mostly responsible for initiating voluntary motions and motion modulation [1]. In such a control mechanism, the CPG network converts the low-dimensional commands from the cortical areas to high-dimensional motor unit commands.

In this research, we try to develop a mathematical CPG model for human motor control analysis. The model can provide a framework to examine the possible ways the CNS controls human body motion.

METHODS

The arm model

- Fixed upper arm
- Periodic motion for forearm/hand
- Three muscle groups
  - Biceps (BIC)
  - Brachioradialis (BRD)
  - Triceps (TRI)
- Constant moment arms

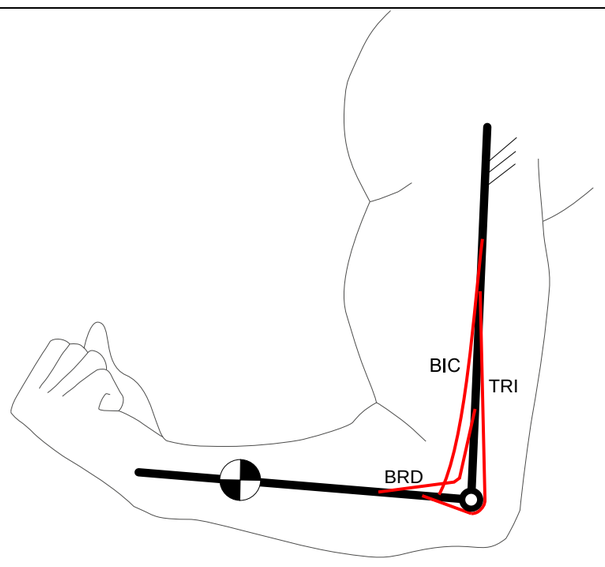

Fig 1 - The forearm model, actuated by three muscle groups

The CPG model

- Based on a pacemaker with tonic input, u

$$\dot{x}_{2,n} = n\,u\,x_1$$
$$\dot{x}_{1,n} = n\,u[\mu(1-x_1^2)x_2 - x_1]$$

- Harmonic number $n = 1\ldots5$
- Muscle force approximation by the modified fifth-order Fourier series:

$$F = a_0 + \sum_{i=1}^{5} a_i x_{2,i} + b_i x_{1,i}$$

- Control the motion frequency by changing pacemaker frequency
- Control the shape of motion by modulating the Fourier parameters (11 parameters for each muscle, 33 in total)

The control strategy

Offline:

- Find the optimal Fourier parameters for a number of motion frequencies
- Generate a map from the desired motion period to the optimal Fourier parameters, from the optimization results

Online:

- Descending command contains the desired motion period
- Proper Fourier parameters are calculated from the offline map
- Pacemaker adjusts the frequency
- Muscle forces calculated through the Fourier series

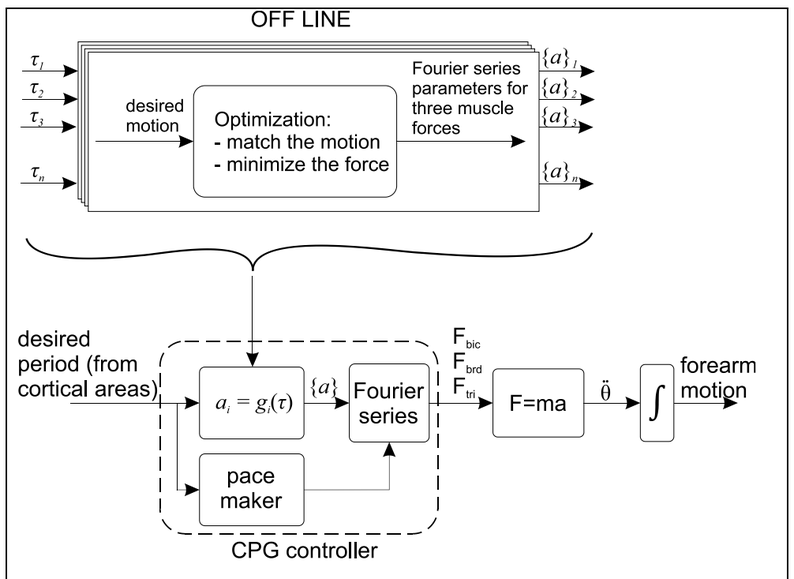

Fig 2 - Block diagram of the control strategy

RESULTS AND DISCUSSION

Fig 3 and Fig 4 show elbow flexion at two different frequencies, along with the muscle forces. The muscle forces are defined by the CPG controller. As can be seen, the controller is able to follow the desired motion by generating very different muscle force patterns.

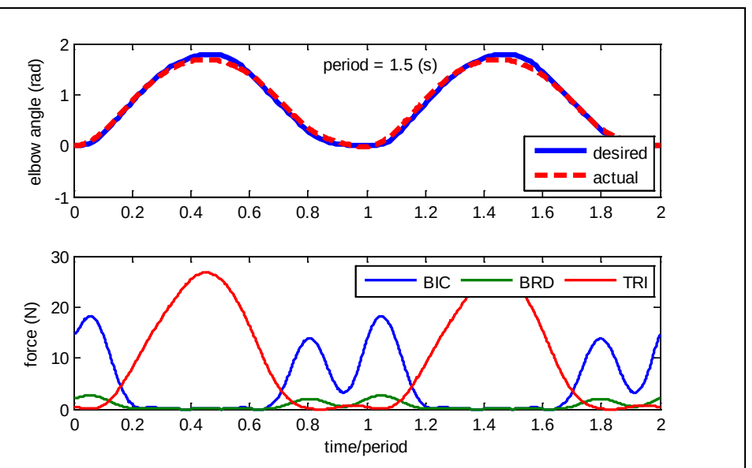

Fig 3 - Elbow angle and muscle forces when period of motion is 1.5 s

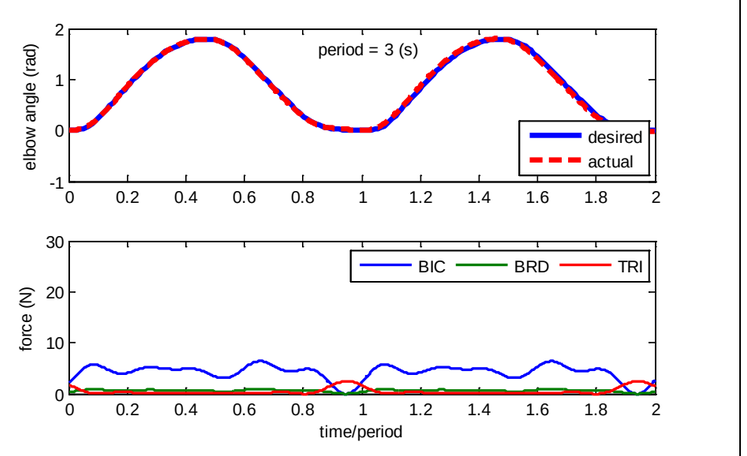

Fig 4 - Elbow angle and muscle forces when period of motion is 3 s

FUTURE WORK

- Introduce feedback to control mechanism
- Include muscle dynamics in the model
- Integrate the concepts of CPG controller and muscle synergy

REFERENCES

[1] Ijspeert A.J. (2008). Central Pattern Generators for Locomotion Control in Animals and Robots: A Review. Neural Networks. 21; p. 642-653

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