An Engineering Interpretation of Natural Movement Control

Lecture 4: EE 546 Winter 2020

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Subsystems for Human Movement

- Mechanical Structure
- Actuators (or Motors)
- **Control System**
  - “Hardware”
  - “Software”
- Sensors
“Systems” View of Control of Movement

- Three main tasks
  - Maintain posture (standing, sitting)
  - Locomotion
  - Hand/Arm Use (one or two)

- Combination of Control Methods
  - Voluntary Motion
  - Background Tasks (e.g., balance while standing)
  - Reflex reactions to stimuli
Movement Control System Organization

- Convert neural information and metabolic energy into movement—to act on environment
- **Sensory info**→**motor commands**→muscle fibers use commands to convert chemical into mechanical energy (by generating contractile forces)
Regulating Posture and Generating Movement

- Muscles contract (and mechanically relax)
- Working together and in opposition, can use muscles to move joints, attain desired stiffness (hence resistance to disturbances)—and to start/stop motions
- Need to efficiently use muscles—trading off motor units to avoid fatigue
Regulating Posture and Generating Movement

- Biology does *Not* explicitly solve multi-dimensional inverse problems computationally
- Pre-programmed patterns, movement command ensembles along constraint surfaces + modifications based on sensor information + reflexes for fast response
Control Structure of Neural Circuitry for Motion

1. Premotor Cortical Areas
2. Motor Cortex
3. Brainstem and reticular formation
4. Spinal Cord
Control Structure of Neural Circuitry for Motion 1--Premotor cortical region

- Planning of movements
  - Identify targets in space
  - Choose course of action
  - “programming” of movement (analogy: like a higher level computer language)
Control Structure of Neural Circuitry for Motion 2—Motor Cortex

- Most processing of motor plans into descending motor commands done here
- Analogy: like a software compiler (sort of)
Control Structure of Neural Circuitry for Motion 3—Brainstem

- Processes relevant sensory information and commands from motor cortex—to generate descending commands for motion
- Integrates/coordinates motor commands
Control Structure of Neural Circuitry for Motion 4—Spinal Cord

- Organization/storage of most automatic responses to stimuli
- Location of controversial “Central Pattern Generator” (CPG) — generating a cyclical signal ensemble used to drive motions such as walking, running, cycling
- **Consequence:** simple descending commands can result in very complex motions
Spinal Cord Components

- **Motor Neurons** — last stage for signals to muscles
- **Intereurons** — provide the computational circuitry for reflexes, coordinated activity of flexors and extensors during locomotion
Circuitry Details

- Simple descending command can
  - Act on motor neurons driving agonist muscle
  - Act on interneurons that inhibit the antagonist muscles
- Descending signals can enhance or suppress reflexes
Modelling Neuron Properties

- Neurons “charge up” to send out signals—a dynamic system with an inherent time delay
- They can be “excited” by some input signals
- They can be “inhibited” by others
- Combinations of these dynamic neurons can result in oscillatory circuits
Fig. 2.2: Combinations of neuronal connections: (A) Collaterals of a single neuron synapse on several target neurons; (B) Activity of a single neuron is the summation of afferent input (1), interneurons (2), and descending fibers (3); (C) An inhibitory command preventing peripheral input from acting on a motor neuron; (D) Descending command controlling afferent input by acting on presynaptic terminals.
Circuits that oscillate

Excitatory neuron (of synergists)—its output goes to motor neurons

Inhibitory Neuron (of synergists)—as it charges up, its output, which inhibits excitatory neuron, increases

Also, as it charges up, its output goes to inhibitory neuron and charges it up
Circuits that oscillate

Additional inhibitory neuron of antagonists—As $E_s$ charges up, it excites $I_a$ -- later, as $I_s$ charges up, it inhibits $I_a$
Circuits that oscillate

Second set of 3 neurons—produces excitatory signal for second set of muscles—note how each circuit inhibits the other—reciprocal inhibition
Computer Simulation of Network

- Each neuron described by 3 differential equations + 5 other equations
- Two oscillatory signals (one to agonists/synergists, other to antagonists)
A cartoon describing this mechanism
Load flexor muscle

muscle forces

extensor muscle

Position
Load

flexor muscle

alpha motor neuron

activation

muscle forces

extensor muscle

alpha motor neuron

activation

Position

muscle forces
Load

flexor muscle

alpha motor neuron

Ib inhibitory interneuron

extensor muscle

alpha motor neuron

excitatory interneuron

muscle forces

Position

activation
Load

flexor muscle

Golgi Tendon Organ

alpha motor neuron

Ib inhibitory interneuron

extensor muscle

Position

muscle forces

activation

activation

activation

excitatory interneuron

alpha motor neuron

interneuron
Load

Position

Golgi Tendon Organ

flexor muscle

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activation

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Golgi Tendon Organ

Ib inhibitory interneuron

excitatory interneuron
Load

flexor muscle

alpha motor neuron

spindle

position

extensor muscle

alpha motor neuron

Ia inhibitory interneuron

activation

muscle forces

activation
Load

flexor muscle

alpha motor neuron

gamma motor neuron

spindle

Position

extensor muscle

alpha motor neuron

Ia inhibitory interneuron

activation

activation
How can electrical stimulation alter this??
[muscle or peripheral motor nerve stimulation]
spinal stimulation
[many in parallel]

stimulation

alpha motor neuron

flexor muscle

activation

muscle forces

extensor muscle

activation

Load

Position

stimulation
References