Internal models for motor control and trajectory planning

Yuhang Mei and Ruifeng Xu

2023.3.8.

Contents

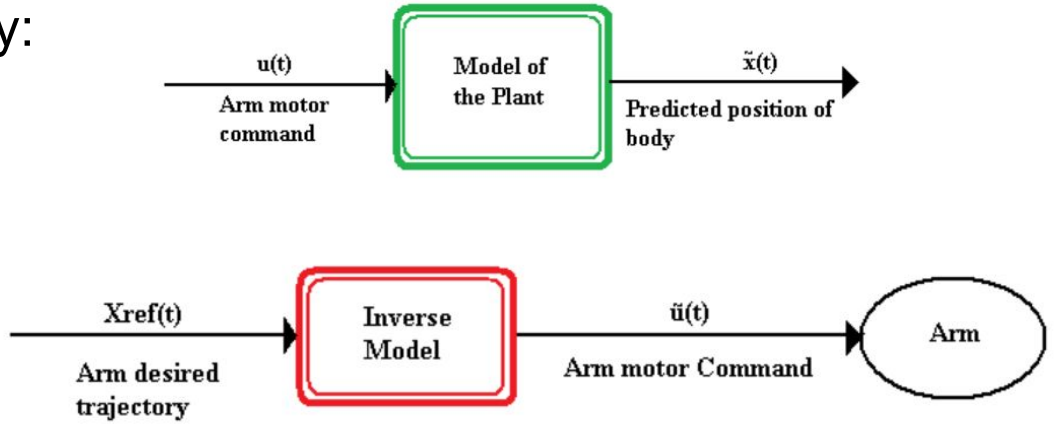
- Introduction
- Existence of internal models
- Internal models in cerebellum
- Structures of internal models
- Trajectory formation
- Discussion

1. Introduction

Definition & Origin

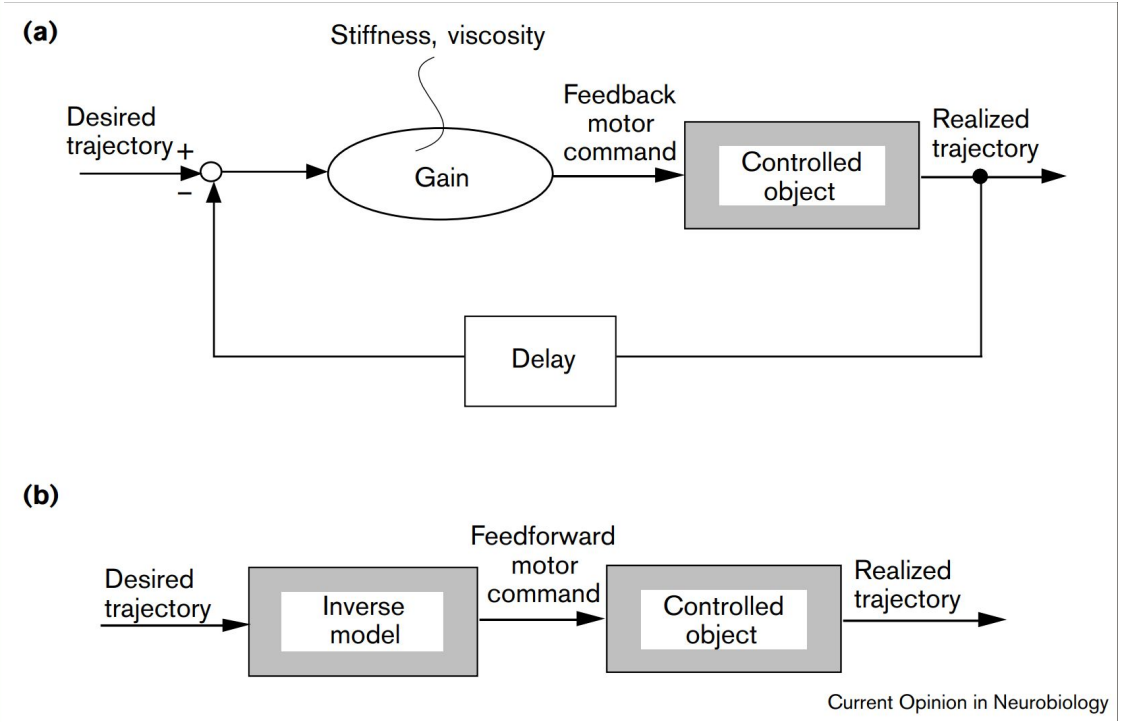
Internal model: neural mechanism that can mimic the input/output characteristics, or their inverses, of the motor apparatus. Including forward internal model and inverse internal model.

In control theory:



2. Existence of Internal Models

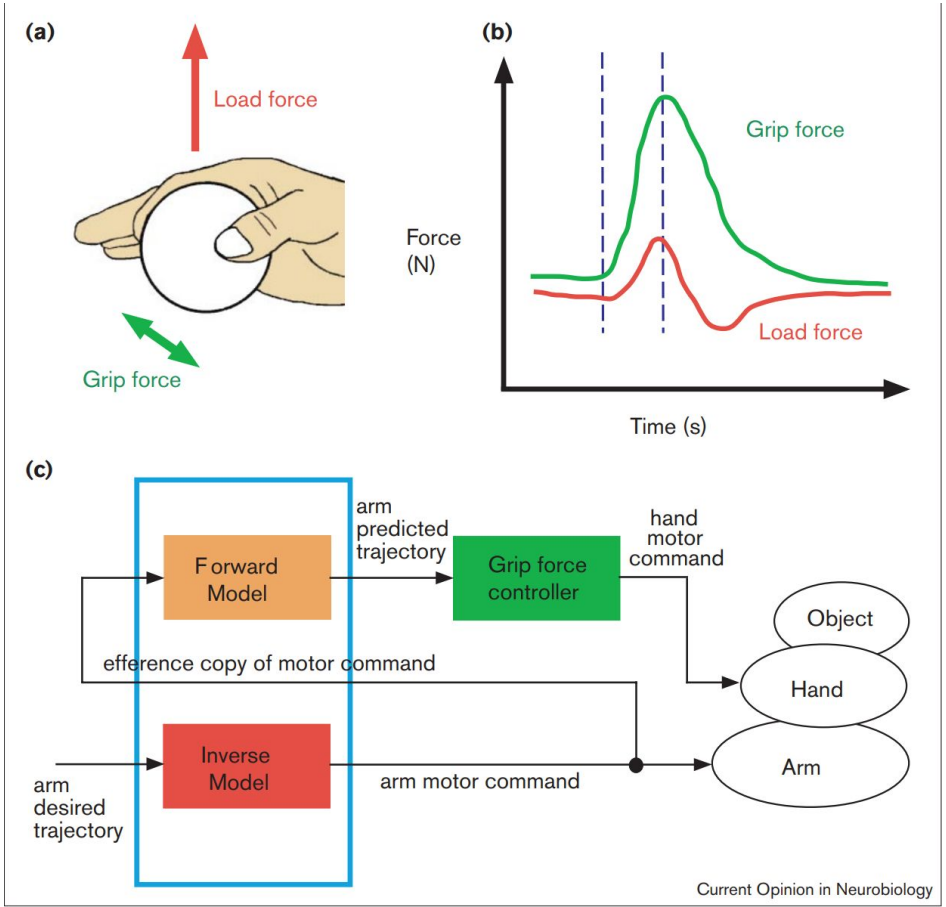
Feedback & Feedforward Control



Biological Motor Control

- Feedback has huge delay
- Huge End-point Error(While removing applied force field suddenly)
- Only computational possibility for fast and well coordinated movements.

Existence of forward models



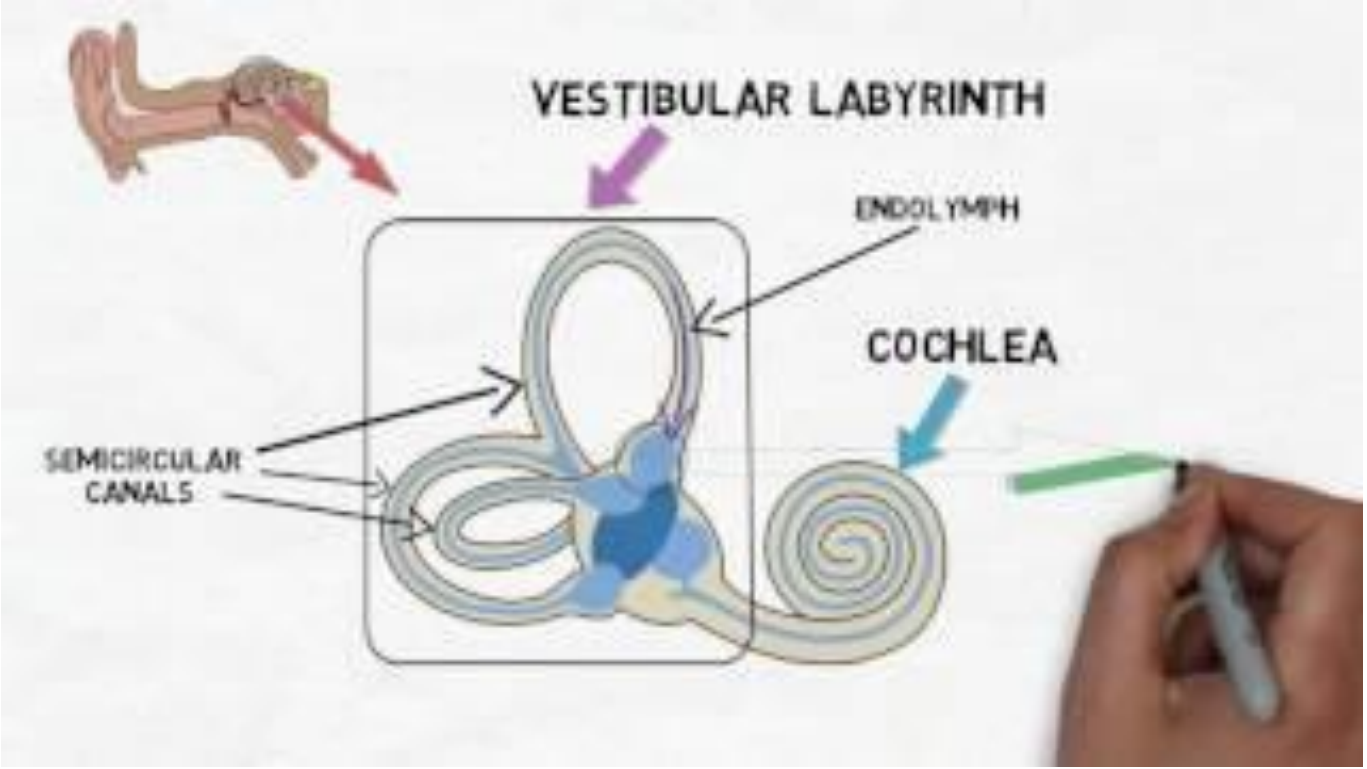
Problem:

(a) Reaching and Grasping

(b) Force field

(c) Existing of forward models in cerebellum by Functional Magnetic Resonance Imaging(fMRI)

Internal Models Studied in Vestibular System



3. Internal Models in the cerebellum

Cerebellar learning theory

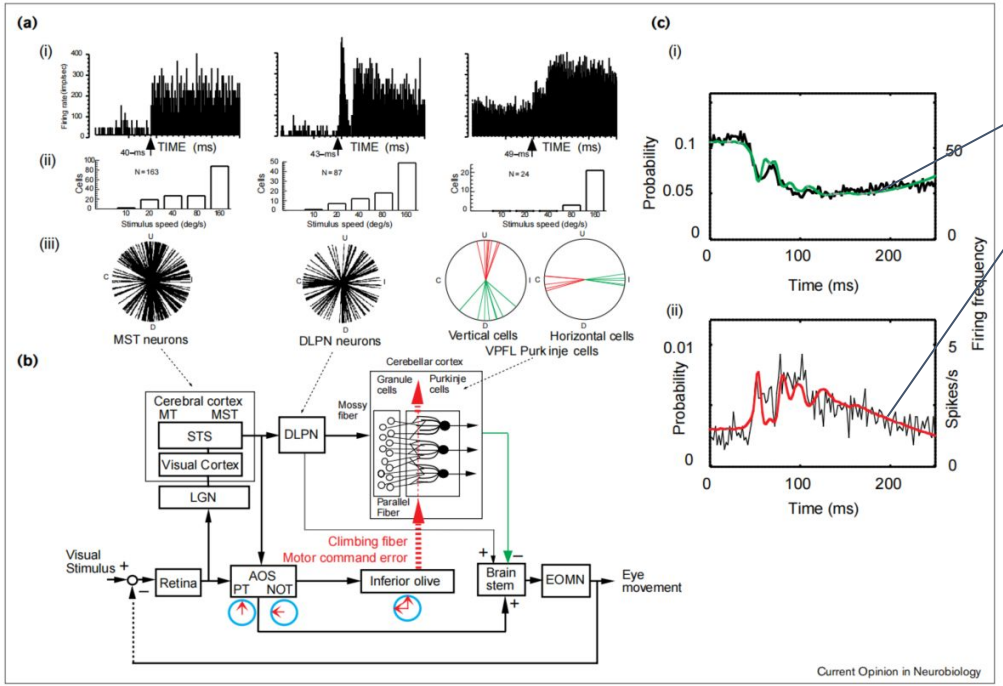
Supervised learning → cerebellum

Reinforcement learning → basal ganglia

Unsupervised learning → cerebral cortex

The learning acquisition of Internal models is best performed by supervised learning, so cerebellar is the most appropriate location.

Neural circuits involved in controlling ocular following responses(OFR)



Black: Accumulated temporal firing patterns of nine Purkinje cells

Green & Red: Inverse dynamics model

Fit well !

Missing link: computational clarification of peculiar physiological and anatomical characteristics of inferior olive neurons

4. Structures of Internal Models

UNIVERSITY OF MICHIGAN

Generalization Experiment

Generalization is perfect: new trajectories are controlled precisely.

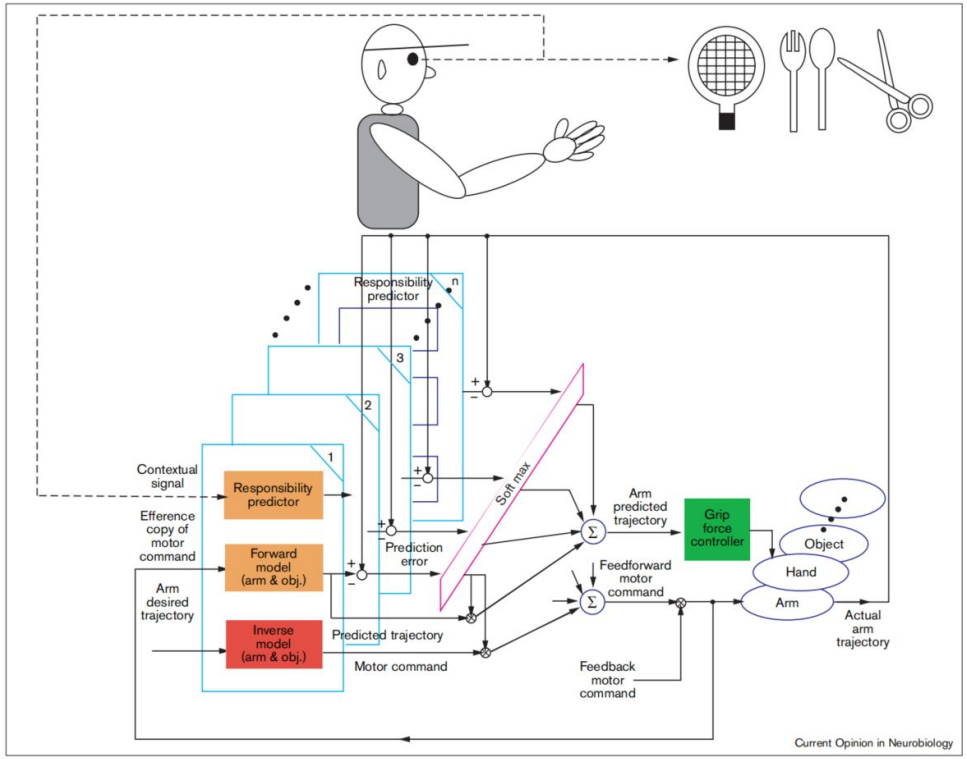
No generalization exists: the inverse dynamics model is a local table-look-up map.

True performance: an intermediate generalization level

It is similar to artificial neural networks or connectionist models' generalization capability.

Suggest modular structures!

New theory: multiple internal models can be learned and combined adaptively



5. Trajectory formation

Ingenious theory: Minimum variance model

Kinematic in its objective function

The computational process is dynamic

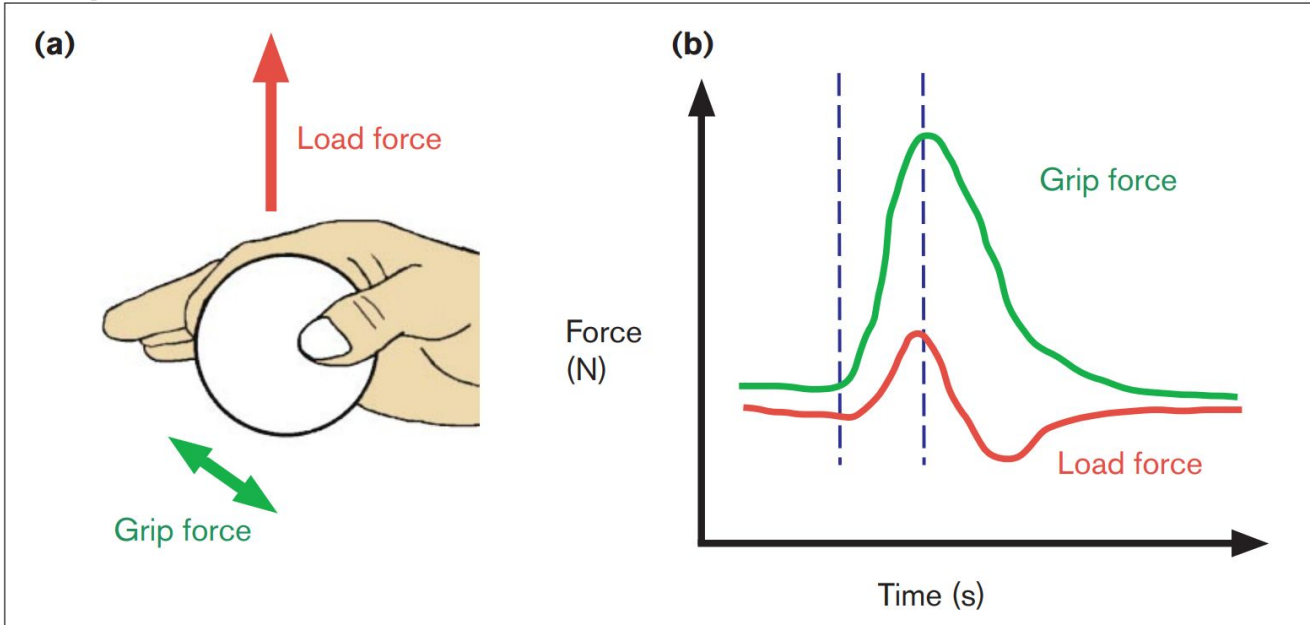
Trajectory depends on the dynamics

This model can be viewed as a version of the minimum motor command change model.

6. Discussion

Discussion Questions

1, @75_f3 It amazes me how our bodies are able to do this prediction/calculation without any seemingly complex functions. One question would be whether humans are **born with a general form of this "calculation equation"** or if humans need to **learn and acquire the correct equation/model through manipulation of the environment**.



Discussion Questions

1, @75_f3 It amazes me how our bodies are able to do this prediction/calculation without any seemingly complex functions. One question would be whether humans are born with a general form of this "calculation equation" or if humans need to learn and acquire the correct equation/model through manipulation of the environment.

Student1: I mean. I am curious about how they get such a ‘calculation equation’. From infants to adult, in which stage will they get such a ‘calculation equation’.

Me: In my opinion, I agree there exist ‘calculation equation’ in humans’ mind. However, I think it will be shown in another way as we thought, not necessary as the ‘calculation equation’. In other words, the internal model and ‘calculation’ equation are similar to two programming language. In one language, the code might be tedious and unreadable, while in the other, the code will be clean and short.

Professor: We should not be trapped into the research bias: we always think we should know everything in the surrounding world to take action, like SLAM or precise locomotion. However, it will always be mistakes to map the surrounding. Besides, just like the refrigerator theory, our sensor should not always be a precise detection. I think it will be the future developing way to take action with few useful features.

Student2: Yes. I think the cucumber cat video I showed last week could be a great example to proof it. The cat might only capture the green color and stick-shape so that they jump(take action).

Discussion Questions

2, For incognitive or unintentional movement, is there still an internal model in cerebellum? E.g. patellar reflex (Knee Jerk Reflex). For trajectory formation, how can we design the controller to adapt to sudden and abrupt change?

UNIVERSITY OF MICHIGAN

Discussion Questions

2, For incognitive or unintentional movement, is there still an internal model in cerebellum? E.g. patellar reflex (Knee Jerk Reflex). For trajectory formation, how can we design the controller to adapt to sudden and abrupt change?

Professor: I think we need to speed up a little bit. I don’t think it is a good point to discuss whether there exists an internal model in cerebellum in such a special situation. I believe those rare cases exist for a reason. Why do you want to dig out more in this case? Just like I said before, we should not be trapped into such a conventional research bias.

UNIVERSITY OF MICHIGAN

Reference

- Kawato, Mitsuo. "Internal models for motor control and trajectory planning." Current opinion in neurobiology 9.6 (1999): 718-727.
- "Internal Model (Motor Control)." Wikipedia, Wikimedia Foundation, 14 May 2022, en.wikipedia.org/wiki/Internal_model_(motor_control). Accessed 7 Mar. 2022.
- "2-Minute Neuroscience: Vestibular System." Youtube, uploaded by Neuroscientifically Challenged, 1 Sept. 2016, www.youtube.com/watch?v=P3aYqxGesqs.
- Eric H. Chudler. "Reflexes." Reflexes, 3 Mar. 2023, faculty.washington.edu/chudler/chreflex.html. Accessed 7 Mar. 2023.