Rhesus Monkeys Learn to Control a 2D Bio-feedback Brain Machine Interface

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Submitted to Journal:
Frontiers in Neuroscience

Specialty Section:
Neuroprosthetics

Article type:
Brief Research Report Article

Manuscript ID:
506845

Received on:
23 Oct 2019

Frontiers website link:
www.frontiersin.org

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

Author contribution statement

CZ and ZL designed the study and wrote the manuscript. CZ, ST, HW, YZ collected the data. CZ analyzed the data.

Keywords

Neural learning, Neural Prostheses, Bio-feedback, brain-computer interface (BCI), Brain-machine interface (BMI)

Abstract

Word count: 245

Brain machine interfaces (BMI) connect brains directly to the outside world, bypassing natural neural systems and actuators. BMIs allow applications such as control of prosthetics or computer cursors. For these applications, researchers have primarily investigated two approaches: bio-mimetic control and bio-feedback control. The bio-mimetic approach relies on increasingly complex algorithms to decode neural activity, in effect mimicking the natural neural systems and actuators bypassed by the BMI. The bio-feedback approach uses simpler algorithms and relies on user learning to facilitate control of novel, non-biological appendages. While some early work in the BMI field used the bio-feedback approach, recent work has been dominated by the arguably more successful bio-mimetic approach. We here study a bio-feedback control method, an approach which we believe will allow users to learn and ultimately gain control superior to that offered by bio-mimetic methods after sufficient training. We implemented a simple firing-rate-to-motion correspondence rule and tested the rule in a 2D cursor movement task. We selected neurons and grouped them according to their directional tuning, and we then used group-wise firing rate sums to directly control cursor speed. Two Rhesus monkeys used this BMI to perform a center-out cursor movement task. After about a week of training, monkeys perform the task better and neural signal patterns changed, indicating learning. While our experiments did not compare this bio-feedback BMI to bio-mimetic BMIs, the results demonstrate our control method is learnable and paves the way for further inquiry into bio-feedback BMIs in future research.

Contribution to the field

Bio-mimetic decoders are widely used in brain-machine interfaces (BMI) based on population neuronal activity. User learning and practice with these decoders are still required with current methods, and we conjecture that the complexity of bio-mimetic decoders may hinder improvement of BMI control through practice. Our work demonstrates that monkeys can learn to use a bio-feedback BMI in a 2D cursor control task. We designed a simple control mechanism, which sums together groups of neurons' firing rates, to convert population neuronal activity to velocity of a multi-dimensional cursor. We trained monkeys to use this control mechanism to complete a center-out behavioral task. Monkeys showed ability to learn this control mechanism, improving their task success rate over about a week of daily practice. Monkeys' neuronal activity also changed after practice. Our results demonstrate the potential of simple bio-feedback BMI for multi-dimensional control and support further investigation of bio-feedback BMIs, as a potential alternative to complex bio-mimetic decoders.

Funding statement

National Key Basic Research Program of China (2014CB846101)
National Natural Science Foundation of China (61431002)
National Natural Science Foundation of China (61401028)
Fundamental Research Funds for the Central Universities (2017XTCX04)

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Keywords: brain-machine interface1, brain-computer interface2, bio-feedback3, neural prostheses4, neural learning5.

Abstract

Brain machine interfaces (BMI) connect brains directly to the outside world, bypassing natural neural systems and actuators. BMIs allow applications such as control of prosthetics or computer cursors. For these applications, researchers have primarily investigated two approaches: bio-mimetic control and bio-feedback control. The bio-mimetic approach relies on increasingly complex algorithms to decode neural activity, in effect mimicking the natural neural systems and actuators bypassed by the BMI. The bio-feedback approach uses simpler algorithms and relies on user learning to facilitate control of novel, non-biological appendages. While some early work in the BMI field used the bio-feedback approach, recent work has been dominated by the arguably more successful bio-mimetic approach. We here study a bio-feedback control method, an approach which we believe will allow users to learn and ultimately gain control superior to that offered by bio-mimetic methods after sufficient training. We implemented a simple firing-rate-to-motion correspondence rule and tested the rule in a 2D cursor movement task. We selected neurons and grouped them according to their directional tuning, and we then used group-wise firing rate sums to directly control cursor speed. Two Rhesus monkeys used this BMI to perform a center-out cursor movement task. After about a week of training, monkeys perform the task better and neural signal patterns changed, indicating learning. While our experiments did not compare this bio-feedback BMI to bio-mimetic BMIs, the results demonstrate our control method is learnable and paves the way for further inquiry into bio-feedback BMIs in future research.

1 Introduction

Brain machine interfaces (BMI), or brain computer interfaces (BCI), connect the brain directly to machines or computers. Here we focus on a subset of such systems which use neuronal recordings from cortically implanted electrodes. Users can use such systems to control robotic arms[i](Chapin et al., 1999)[ii](Velliste et al., 2008)[iii](Hochberg et al., 2012)[iv](Balasubramanian et al. 2013), cursors on computers[v](Serruya et al., 2002)[vi](Li Z et al., 2009)[vii](Gilja et al., 2015)[viii](Pandarinath et al., 2017) or tablet [ix](Nuyujukian et al., 2019), exoskeletons [x](Vouga et al., 2017), and their own paralyzed

运动皮层植入式脑机接口的非线性解码算法综述

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摘要
运动皮层植入式脑机接口（BMI）可将来自大脑运动区域的神经信号转换为控制信号以操纵外部设备，其可以提供对人工假肢等直接神经控制来改善瘫痪患者的生活质量。本文综述近年来运动皮层植入式 BMI 的一些经典非线性解码算法，首先简要介绍运动皮层脑机接口实验范式、解码器的评估方法，接着详细介绍回声状态网络、长短期记忆网络、无迹卡尔曼滤波器、粒子滤波器、点过程滤波器等常用解码算法，最后对未来解码器的发展做展望。

关键词：脑机接口；解码算法；运动皮层
中图分类号: 文献标志码: A DOI:

Review of nonlinear decoding algorithms for motor intracortical brain-machine-interfaces

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Abstract: The motor cortex implantable brain-computer interface (BMI) can convert the nerve signals from the brain motor area into control signals to manipulate external devices. It can provide direct nerve control on artificial prostheses and other devices to improve the quality of life of paralyzed patients. This article reviews some classic non-linear decoding algorithms of the motor cortex implanted BMI in recent years. First, we briefly introduce the experimental paradigm of the motor cortex brain-computer interface, the evaluation method of the decoder, and then introduce in detail the common decoding algorithms such as echo state network, long short-term memory network, unscented Kalman filter, particle filter, and point process filter. Finally, Look forward to the development of decoders in the future.

Key words: brain-machine-interfaces, decoding algorithm, motor cortex

基金项目：国家重点基础研究发展计划(2014CB846101)；国家自然科学基金(61401028)；中央高校基本科研业务费专项资金(2017XTCX04)

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软 件 名 称：基于安卓的个性备忘录软件
[简称：MyMemo]
V1.0

著 作 权 人：安徽师范大学

开发完成日期：2018年03月15日

首次发表日期：未发表

权利取得方式：原始取得

权 利 范 围：全部权利

登 记 号：2018SR725750

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2018年09月07日

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[简称：BusInfo]
V1.0

俞汉友

著 作 权 人：安徽师范大学

开发完成日期：2017年03月30日

首次发表日期：未发表

权利取得方式：原始取得

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2017年06月21日