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A relation spectrum inheriting Taylor series: muscle synergy and coupling for hand

Key words: Taylor series; Relation spectrum; Dendrite net (DD); Prosthetic hands; Machine learning; Engineering

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Motivation

(Tools) There are two famous function decomposition methods in math: the Taylor series and the Fourier series.

- The Fourier series developed into the Fourier spectrum, which was applied to signal decomposition and analysis.
- However, because the Taylor series function cannot be solved without a definite functional expression, it has rarely been used in engineering.

Specific engineering:

- Knowledge of the intuitive link between the muscle activity and finger movement is vital for the design of commercial prosthetic hands that do not need user pre-training. However, this link has yet to be understood due to the complexity of the human hand.

Main idea

Tools:

- We developed a Taylor series-like relation spectrum using our proposed Dendrite net (DD) and applied it to the decomposition and analysis of models and systems.

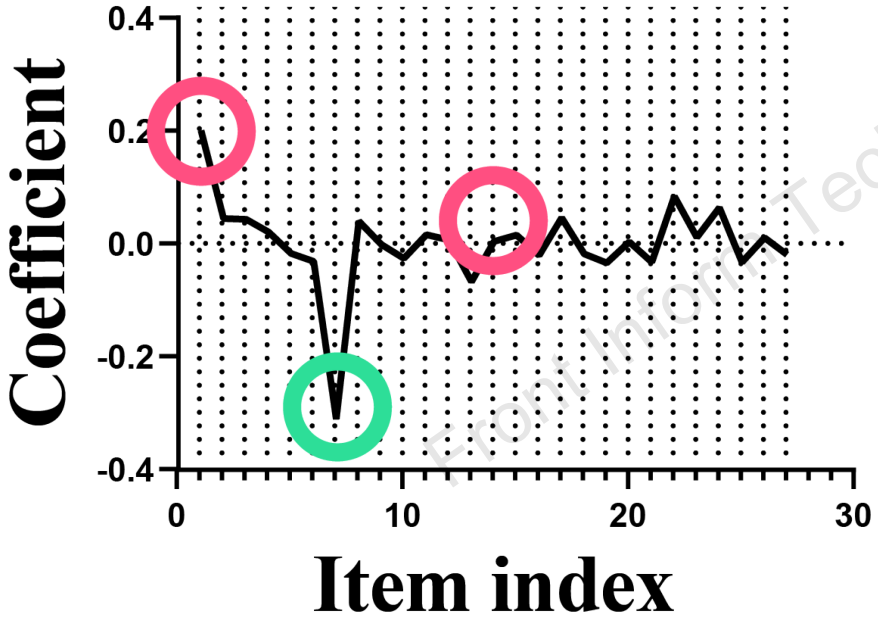
Specific engineering:

- We decomposed the muscle-finger system into a relation spectrum.

- We analyzed the muscle synergy and muscle coupling for the hand by relation spectrum.

Relation spectrum

The trained DD model was translated into the relation spectrum. Then, we analyzed the model and system by relation spectrum.



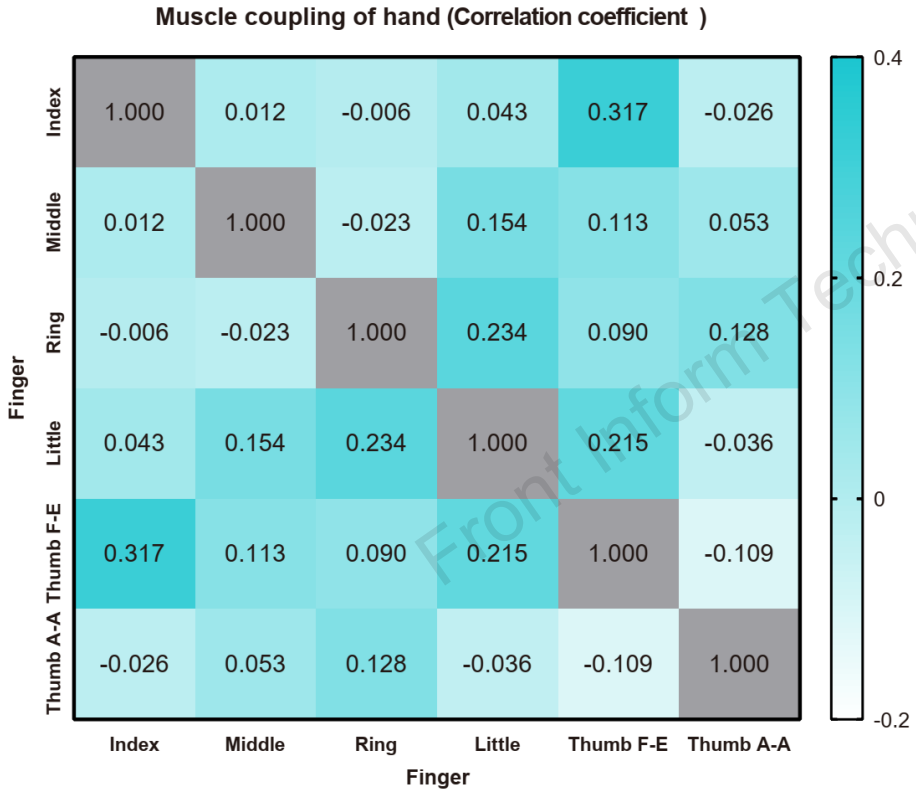
Relation spectrum of the muscle–finger system (example)

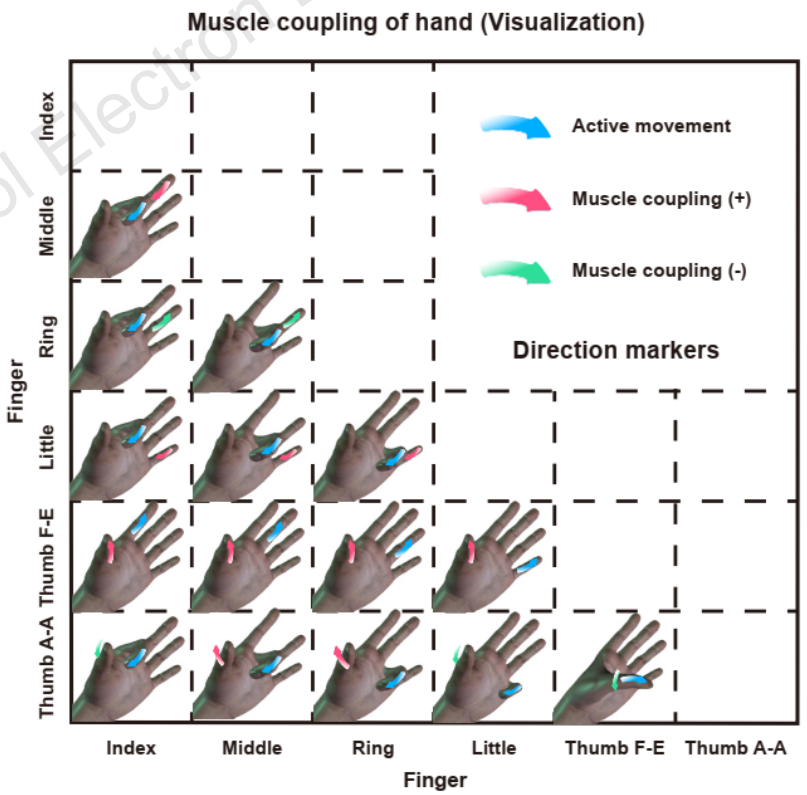
Table 1 Items in the relation spectrum

Index	Item	Index	Item
1	E_{FPL}^2	15	$E_{\mathrm{EDC}}E_{\mathrm{EPL}}$
2	$E_{\mathrm{FPL}}E_{\mathrm{FDP}}$	16	$E_{\mathrm{EDC}}E_{\mathrm{EIP}}$
3	$E_{\mathrm{FPL}}E_{\mathrm{EDC}}$	17	$E_{\mathrm{EDC}}E_{\mathrm{APL}}$
4	$E_{\mathrm{FPL}}E_{\mathrm{EPL}}$	18	E_{EDC}
5	$E_{\mathrm{FPL}}E_{\mathrm{EIP}}$	19	E_{EPL}^2
6	$E_{\mathrm{FPL}}E_{\mathrm{APL}}$	20	$E_{\mathrm{EPL}}E_{\mathrm{EIP}}$
7	E_{FPL}	21	$E_{\mathrm{EPL}}E_{\mathrm{APL}}$
8	E_{FDP}^2	22	E_{EPL}
9	$E_{\mathrm{FDP}}E_{\mathrm{EDC}}$	23	E_{EIP}^2
10	$E_{\mathrm{FDP}}E_{\mathrm{EPL}}$	24	$E_{\mathrm{EIP}}E_{\mathrm{APL}}$
11	$E_{\mathrm{FDP}}E_{\mathrm{EIP}}$	25	E_{EIP}
12	$E_{\mathrm{FDP}}E_{\mathrm{APL}}$	26	E_{APL}^2
13	E_{FDP}	27	E_{APL}
14	E_{EDC}^2	28	1

Muscle coupling of the hand

We analyzed the muscle coupling for the hand by relation spectrum.





Contributions

Tools:

- The relation spectrum makes the online model human-readable, which unifies online performance and offline results.

Specific engineering:

- The findings concerning the hand contribute to the design of prosthetic hands.

Outlook

Tools:

- Although this relation spectrum and DD, like SVM, are very basic, they have the potential to be applied in most engineering fields.

Table 2 Comparison of typical algorithms

Algorithms	Readability	Classification or regression (online)	Analysis (offline)
SVM, traditional NN, etc.	Black box	Yes	No
Fourier transform and Fourier spectrum	White box	No	Yes (decomposing signal)
Dendrite net and relation spectrum	White box	Yes	Yes (decomposing system/model)

The relation spectrum makes the online model human-readable, which unifies online performance and offline results. The relation spectrum is interpreted according to the specific application, just like the Fourier spectrum.

Gang LIU is currently pursuing the PhD degree in engineering from the Institute of Robotics and Intelligent Systems, iHarbour Academy of Frontier Equipment, Xi'an Jiaotong University, China. He is the Advisor to IOP Publishing and reviewers for *IEEE Transactions on Signal Processing*, *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, *Journal of Neural Engineering*, etc. He presented the dendrite net, relation spectrum, and improved neurons. His research interests include machine learning, deep learning, computer vision, natural language processing, and brain-computer interface.

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