Synergies and Exploratory Procedures for Haptic Object Recognition

April 2023

Abstract

The purpose of this article is to study the role that synergies play in the characterization of movements and exploratory procedures we perform while exploring different objects through touch. These synergies have been proposed as a good tool for describing such movements as well as the method used by the central nervous system to control the high-dimensional space of the hand. We will analyze if this approach provides an advantage in describing the exploratory procedures and the hand movements in an open exploration of an object. We will also create different mathematical/machine learning-deep learning models to study exploratory procedures and their relationship with certain physical characteristics of the objects to be explored. Finally, the results of different classification methods present in the literature are analyzed and discussed to elucidate the advantages and disadvantages that each of them presents.

Keywords

"Active Object Exploration", "Exploratory Procedures", "Postural Synergies"

Classification by Raw Data

The idea is to build different classifiers (logistic regression and time-series) using the raw data from the different sources that we have, compare their performances and check which is the most adequate methodology to apply.

Methods:

- Build a logistic regression classifier and a time-series DL based classifier using each source (motion tracking, EMG & tactile) and compare results.

- For the logistic regression classifiers, extract and study the most relevant variables and if their weight difference is significant or not (between variables inside the same family, between families, ...). Since we have very few trials per subject, comparing between subjects might not be useful.
- Study weight evolution over time.
- Build logistic regression and time-series classifiers from the combination of sources, compare results between combinations and methods (multisource vs. hierarchical) and study if accuracy differences are significant.
- It can be interesting to compare the raw EMG with the same classifier but based in feature extraction as in *Leo et al.* [1] both in logistic regression and time-series classifiers.
- It can be interesting to compare raw single source vs. normalized single source.
- It can be very interesting to explore early enclosure classification with raw kinematics and EMG (as in *Scano et al.*) [2].

Expected results & discussion:

For the logistic regression classifiers, preliminary results (with trials divided into EPs) show poor ($\sim 50\%$) but above chance classification accuracies for within-group classification. Time-series classifiers perform very good for within-group but not when we try to classify among all objects. Hierarchical classifiers seems to be a little better than single-source or multimodal classifiers for logistic regression. The hierarchical approach has not been tested yet on time-series classifiers but the multimodal classifier outperforms the single-source. Tactile data seems to confound the classifier. Although this section does not present any significant advances in this research field, both the complexity of the experimental task and the methodological issues addressed in it do represent a considerable novelty. If we perform also classification based on early enclosure we can compare to all those synergy studies based on reach & grasp or virtual grasping and overcome the problem with the difference in trial lengths.

Synergies

Synergies were defined by Bernstein in 1967 [3] and proposed as an interesting way to describe and characterise hand movements on a kinematic and muscular level [4]. *Thakur et al.* thought of synergies as "building blocks of EPs" [5]. They have also been proposed as the basic patterns used by the CNS to control hand postures [6]. The purpose of this section is to find these synergies and see if they can be used as a good descriptor of hand movements even for more complex tasks like ours. We also want to study if those synergies are shared between subjects and tasks and if they constitute "the building blocks" of EPs.

In this section we will be using again the logistic regression and the time-series classifiers.

Methods:

- Extract synergies using different methods for each source (PCA for kinematics, NMF for EMG, ...).
- Study if these synergies are shared between subjects, objects, families, trials, EPs, ...
- Classify objects based on those extracted synergies and compare it with previous classifiers with raw data (including multisource and hierarchical).
- Study how the classification accuracy decays as we drop synergies.
- For the EMG, extract the synergies not from the raw data but from the EMG features (as in *Leo et al.* [1]) and then classify. Compare that classifier with the previous classifiers from EMG data.
- Compare the most relevant variables in the most relevant synergies with the variable weights in previous classifiers.
- Compare different methodologies when extracting the synergies (normalize or not, extract synergies from each subject and build clusters or extract synergies from the entire dataset) as mentioned in *Gracia-Ibañez et al.* [7].
- Extract synergies from early enclosure and build classifiers using them using them. Compare the obtained synergies between subjects, objects, families, ...

Expected results & discussion:

We expect to find that the precision remains at acceptable levels even after considerably reducing the dimensionality of the problem. Preliminary results show that synergy patterns are not shared among EPs, objects or subjects. This section can give us some ideas of how this method based on synergies behaves in more complex tasks, providing evidence about its possible utility or application. In case synergies are good describers for early enclosure (se seen in literature) but the number of synergies necessary to describe the entire trial is close to the number of dimensions in the original space, it could be argued that this approach is only a "mathematical artifact" and would not have any advantage for the CNS when it comes to controlling the motor system in general and the hand movements in particular.

Classification by EPs used

The intention is to build classifiers based on the EPs performed by the subject during the exploratory task. These three classifiers would be based on presence/absence, the number of occurrences and the time duration of the EPs. The internal weights of that classifiers would give us an idea of which EPs are most relevant. Since each EP is associated with some physical properties we want to connect the most relevant EPs with those physical properties that are relevant to discriminate the objects.

Methods:

- Build three different logistic regression classifiers (binary, count, execution time) to predict the object within the family and the same three classifiers to predict among families.
- Extract and analyse the model weights to find the EPs that the model considers relevant. Study if weight difference is significant or not (between variables inside the same family, between families, ...). Again, since we have very few trials per subject, comparing between subjects might not be useful.
- Compare results and weights between classifiers.
- Compare the properties associated to the most relevant EPs for each object and family with the physical property that discriminates those objects the most.
- Compare results with those presented by *Lederman & Klatzky* [8, 9].

Expected results & discussion:

We have some preliminary results that supports the findings presented by *Lederman & Klatzky* [8, 9]. Even though these results are not very solid (classification accuracy is low but above chance level) we can present this as a "quantitative" approach to their work and new evidence in favour of their hypotheses.

References

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