

Learning Strategies for Anthropomorphic Hands in a Synergy-based Framework

Fanny Ficuciello, Damiano Zaccara, Bruno Siciliano

I. INTRODUCTION

New generation of robots should have comparable abilities to deftly move in different environments, autonomously learn and make decisions. The use of anthropomorphic hands has become a key breakthrough in advanced robotics involving both humanoid robots and prosthetic applications. An efficient and forefront design of advanced robotic hands requires solving a compromise among size and weight, functional dexterity and control complexity. Advanced mechatronic structure and high number of degrees of freedoms (DoF) are essential to change different configurations and adapt to the environment. On the other hand, design and control complication due to high DoF can be somewhat offset by means of coordinated motion that help to simplify robot hardware and software. This can be summarized by saying that the robot must be equipped with embodied intelligence. A solution to the problem can be found in designing underactuated devices and comes down to choosing the optimal number of motors as well as the motion couplings between fingers and joints. However, underactuated hands require the investigation of planning and control methods that disregard accurate definition of the desired contact points on the object and guarantee robustness with respect to variability of shape and size. To overcome these problems, synergies concept is used to develop control and learning algorithms. The synergy concept is useful for innovative underactuated design of anthropomorphic hands and is a powerful tool to plan grasps and control artificial hands both fully-actuated and underactuated, i.e. already provided of their own mechanical synergies.

II. SYNERGIES SUBSPACE

Several methods have been proposed to compute the synergies subspace. In [1], the basis space of synergies is represented by a matrix of constant eigengrasps (basis of eigenvectors) and refers to fully actuated anthropomorphic hands. Here, the experimental results highlight that, despite the differences in kinematics and mapping methods, the first three synergies have some basic features that are preserved if the hand kinematics is anthropomorphic and if the grasps data set is suitably chosen to cover a large variety of human grasping

postures. The method adopted in [1] is based on a joint-to-joint mapping technique where the hand configurations are manually adjusted in order to imitate as much as possible the human hand desired configuration. Thus, the method strongly depends on the interpretation of the reference grasp by the operator and on his/her ability to reproduce the grasp with the robotic hand. To overcome this limitations, in [2] a new model-based method to map grasps from the human to the robotic hand has been developed. A set of grasping postures performed by five subjects in grasping commonly used objects has been mapped to a robotic hand. The core idea of the mapping method is to dramatically simplify the detection of the human hand posture by measuring strategic points using a low cost camera and using the robotic hand kinematics as a paradigmatic model of the human hand for inverse kinematic computation. In [3], the same data set of grasps, measured on five human subjects and available from [2], is used to evaluate the grasping capabilities of an *underactuated robot hand* in a synergy-based framework. Once the synergy matrix of an underactuated hand has been computed, in order to test the efficiency of the mapping method, different grasps will be reproduced in the three dimensions synergies subspace. In [3] the kinematics and the mechanical synergies of the underactuated *SCHUNK five-finger hand* are considered for the theoretical formulation and for the experiments. Nevertheless, the study can be extended to any underactuated kinematics of anthropomorphic hands. Actually, since mechanical synergies affect the mapping from the human hand, the projection of a grasp from the data set in the synergies subspace is not so effective as for the full-actuated anthropomorphic hands [2]. Thus, the reproduction is not successful for all the grasps. This means that a control strategy is required to adjust the reference grasp in order to let the hand adapting to the object while moving in the synergies subspace. The synergies subspace has been tested for the hand control using a CLIK algorithm based on the synergies Jacobian. A simple strategy to modify the reference grasp can be adopted. The fingertips desired positions are modified in the control algorithm in order to reduce their distance with respect to the centroid of a virtual object computed as the centroid of the fingertips involved in the desired grasp. Moreover, in order to limit the grasping forces, the desired target of the CLIK is modified on the basis of the measured motor current and of a defined threshold that is related to the texture of the object. The experiments demonstrate that the synergies subspace is suitable for hand control in grasping a wide variety of objects, i.e. the algorithm is stable and effectively regulates the grasping forces by modifying the motor positions in the synergies subspace.

The authors are with PRISMA Lab, Department of Electrical Engineering and Information Technology, University of Naples Federico II, via Claudio 21, 80125, Naples, Italy, email: {fanny.ficuciello, bruno.siciliano}@unina.it, damianozaccara@libero.it. The research leading to these results has been partially supported by the RoDyMan project, funded by the European Community's Seventh Framework Programme (FP7/2007-2013) under ERC AdG-320992. The authors are solely responsible for the content of this manuscript.

III. LEARNING

Synergies might also be useful in conjunction with the learning process [4], [5]. This aspect is less explored since few works on synergy-based learning have been realized in robotics. In learning new tasks through trial-and-error, physical interaction is important. Consequently, advanced mechanical designs enhance capabilities of adapting to changing environments and learning from exploration while increase the complexity of modelling and control. Analytic approach to manipulation planning requires a precise model of the object, an accurate description of the task, and an evaluation of the object affordance, which all make the process rather time consuming. The integration of learning into control naturally leads to relaxing the above requirements through the adoption of coordinated motion patterns and sensory-motor synergies as useful tools leading to a problem of reduced dimension. To this purpose, model-based control strategies relying on synergistic models of manipulation activities learned from human experience can be integrated with real-time learning from actions strategies. The use of supervised learning, such as artificial neural networks, or reinforcement learning techniques, serves for the parameterization of synergies depending on task requirements.

1) *Supervised Learning (SL)*: In [6] a multilayer feedforward neural network with non linear transfer function has been adopted. The use of synergies reduces the search space of the learning algorithm addressing a simplification in the neural network architecture design, especially regarding the number of hidden layers and the neurons in each of them. As a result of experimental evaluations, the network model has been chosen as a feedforward NN with two hidden layer and ten sigmoid neurons for each layer. To improve the generalization, multiple neural networks have been trained and an average of their outputs has been considered for the experiments. The experiments demonstrate that multiple neural networks are able to approximate with a high quality level the relationship between the synergies coefficients and the geometrical object features distinguishing among precision, power and lateral grasps, and also the number of fingers involved.

2) *Reinforcement Learning (RL)*: From recent research in the field it seems that RL represents the future toward autonomous and intelligent robots since it provides learning capabilities as those of humans, i.e. based on exploration and trial-and-error policies. In [7] is demonstrated that a synergy-based approach is powerful for reinforcement learning of grasping with anthropomorphic hands due to configuration space dimensionality reduction that guarantees the convergence and efficiency of the learning algorithm. The design of appropriate policy representations is essential for RL methods to be successfully applied to real-world robots. PCA and human grasps data set serve as data structures to define a policy and its initial parameters for a RL algorithm. Indeed, starting from a good enough demonstration, the algorithm can optimize the policy parameters to gradually refine a stable grasp. When a clear measure about the success of the task is available, RL adaptability to new objects is ensured. A key point is the adoption of a suitable reward function representing the goal

of the task and ensuring one-step performance evaluation. In [7] as a cost function, force closure quality of the grasp in the synergies subspace has been chosen.

IV. CONCLUSION

A question that often arises, among researchers working on artificial hands and robotic manipulation, concerns the real meaning of synergies. Namely, are they a realistic representation of the central nervous system control of manipulation activities at different levels and of the sensory-motor manipulation apparatus of the human being, or do they constitute just a theoretical framework exploiting analytical methods to simplify the representation of grasping and manipulation activities? Apparently, this is not a simple question to answer and, in this regard, many minds from the field of neuroscience and robotics are addressing the issue. The interest of robotics is definitely oriented towards the adoption of synergies to tackle the control problem of devices with high number of DoF which are required to achieve motor and learning skills comparable to those of humans.

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