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Knowledge-based reasoning from human grasp demonstrations for robot grasp synthesis

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ABSTRACT

Humans excel when dealing with everyday manipulation tasks, being able to learn new skills, and to adapt to different complex environments. This results from a lifelong learning, and also observation of other skilled humans. To obtain similar dexterity with robotic hands, cognitive capacity is needed to deal with uncertainty. By extracting relevant multi-sensor information from the environment (objects), knowledge from previous grasping tasks can be generalized to be applied within different contexts. Based on this strategy, we show in this paper that learning from human experiences is a way to accomplish our goal of robot grasp synthesis for unknown objects. In this article we address an artificial system that relies on knowledge from previous human object grasping demonstrations. A learning process is adopted to quantify probabilistic distributions and uncertainty. These distributions are combined with preliminary knowledge towards inference of proper grasps given a point cloud of an unknown object. In this article, we designed a method that comprises a twofold process: object decomposition and grasp synthesis. The decomposition of objects into primitives is used, across which similarities between past observations and new unknown objects can be made. The grasps are associated with the defined object primitives, so that feasible object regions for grasping can be determined. The hand pose relative to the object is computed for the pre-grasp and the selected grasp. We have validated our approach on a real robotic platform—a dexterous robotic hand. Results show that the segmentation of the object into primitives allows to identify the most suitable regions for grasping based on previous learning. The proposed approach provides suitable grasps, better than more time consuming analytical and geometrical approaches, contributing for autonomous grasping.

1. Introduction

As humans stand out in manipulation tasks – a basic skill for our survival and a key feature in our manmade world of artefacts and devices – human manipulation actions and choices can be observed, learned and used to allow a robot with cognitive skills to interact and manipulate objects in our environment. In this work we address an artificial system for grasp synthesis useful for autonomous grasping. The proposed approach relies on knowledge from previous human grasping of pre-defined objects recorded from both human hand and objects' points of view. A learning process is adopted to quantify the probability distributions and the uncertainty over the human grasp experiences. These distributions are combined with preliminary knowledge of grasping choice for specific object shapes towards inference of proper grasping given an object point cloud coming from the sensor observations (RGB-D camera). To accomplish our goal of generating grasp hypothesis given an unknown object, our system is designed in a twofold process: object decomposition and grasp synthesis. This way, after the object decomposition we can find suitable regions for grasping, as well as the candidate grasps for this object. Fig. 1 depicts an overview of our proposed approach.

In a first stage, the decomposition of objects into geometrical shapes is used, across which similarities between past observations and new unknown objects can be made. Afterwards in a second step, the grasp synthesis process generates a list of candidate grasps for the given object. To grasp an object using an articulated hand, we can face the problem of a huge number of grasp configurations possibilities due to the number of degrees of freedom of

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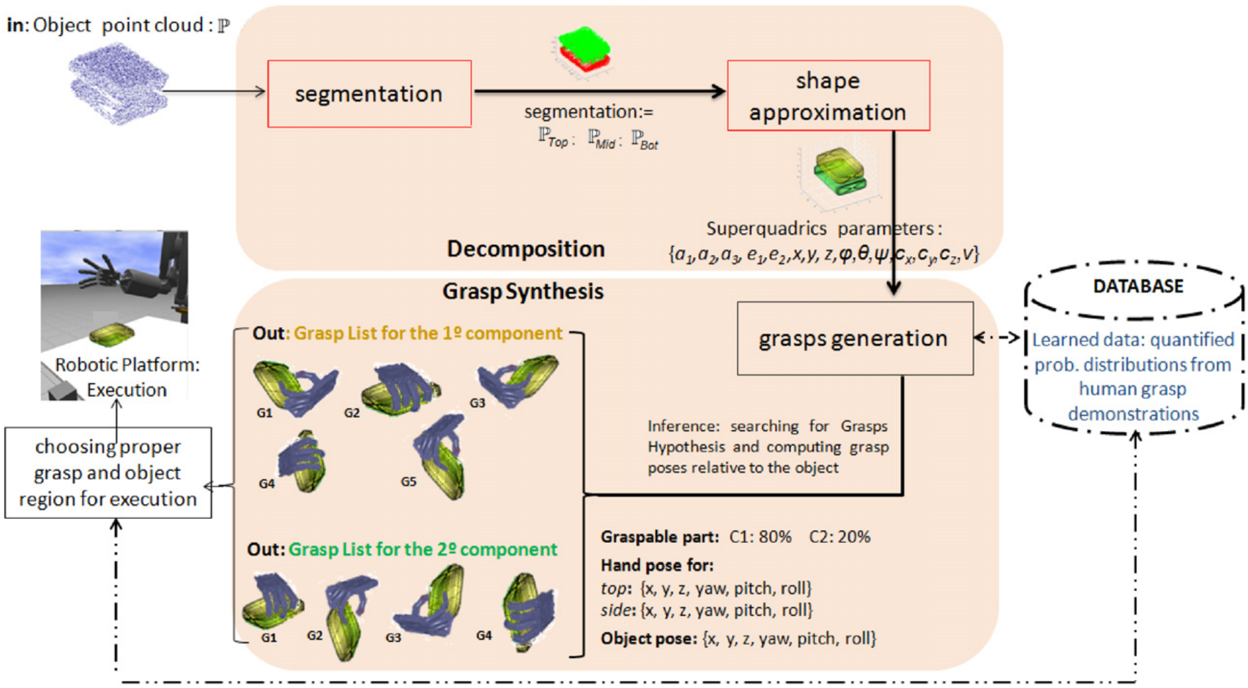

Fig. 1. Overview of our proposed approach, broken down into object decomposition and grasp synthesis modules.

the hand. A way to simplify this problem is to adopt a grasp taxonomy that encloses hand configurations that are often used by humans to grasp specific object shapes in different contexts. This way, an object shape can be associated with grasp types by observing humans performing some tasks. We are limiting the huge amount of candidate grasps into a smaller set of probable grasps, since we are simplifying the object shape into primitives and using a subset from a taxonomy of human grasp types. We are using a pre-defined grasp list comprising of 33 grasp types [1] that can also be used for unknown objects. Given a set of hand configurations for a specific object shape, the hand poses relative to the object is computed for the selected grasp from the hypothesis list generated for the object. Using this strategy, we have validated our approach on a real robotic platform — a dexterous robotic hand [2].

This work contributes with a solution that integrates different techniques into a single framework to achieve a full system of grasp synthesis, starting from the object model acquisition up to the grasp execution, that at each step minimizes processing time so as to have an acceptable robot performance time. The artificial system relies on the fact that humans use previous partial knowledge and naturally grasp objects in a stable and proper way in different circumstances, such as objects that differ in size, geometry and orientation. We introduce an ad-hoc solution for object segmentation and subsequent approximation of each of the object components with a geometrical primitive. This breakdown allows matching these primitives with known object components for which sets of viable grasps are known. We introduce a learning stage where the system, given the sensors readings, automatically labels the contact points and object graspable regions using an occupancy grid-based method. The learning stage indexes the graspable regions with a set of candidate grasps. A probabilistic framework is presented in such a way that previous observed knowledge is used for decision making on how to grasp an unknown object.

This article is organized as follows: Section 2 describes related work; Section 3 describes the object segmentation and shape approximation given an object point cloud to define object components for grasping. Section 4 presents how we use the human demonstrations to learn relevant information for reasoning, i.e., inferring how to generate proper grasps for a specific object, and estimating the proper region on the object for grasping. Section 5 presents the grasp synthesis architecture that encloses the steps mentioned in previous sections and the generation of grasp pose relative to the object. Section 6 presents the experimental results, including simulations and also an example in a real application using a dexterous robotic hand. Section 7 draws some conclusions and presents future work directions.

2. Related work

Grasp synthesis can be achieved by analytical or empirical approaches. Analytical approaches select the finger positions and hand configurations with kinematical and dynamical formulations. Thus, they generally optimize an objective function such as the grasp stability or the task requirements. On the other hand, empirical (knowledge-based or data-driven) approaches use a learning strategy to choose grasps that depend on the task and on object shape. They rely on sampling candidate grasps for an object and ranking them according to a determined measure or metric [3]. An important factor that needs to be considered in the development of robotic grasping is ensuring stability during the object grasping. There are many approaches for robotic grasping that try to solve this problem, but constraints are encountered. One is finding suitable stable grasps where the task requirements are involved, making the process more complex. To model a robotic grasping, generally, a set of constraints has to be satisfied. First, the robotic hand kinematics and capabilities must be considered. Second, the object features must be taken into account. Finally, the constraints of the task requirements must be analyzed.

When dealing with Learning-by-Demonstration strategies, we can find different works in the literature where the robot observes a human performing a task and afterwards it is able to perform the task by itself. Examples of kinaesthetics demonstrations for learning and generalization, and situated multimodal interaction to teach a robot are demonstrated by [4,5], respectively. Mirror neurons modelling is also a possibility when observing an action in grasping context as demonstrated by [6]. One of the difficulties arising in human based learning is how to measure human performance. Many researchers use data gloves for mapping of human hand to artificial hand workspace and learn the different

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