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Contents

From Specialized Industrial Grippers to Flexible Grippers: Issues for Grasping and Dexterous Manipulation

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ABSTRACT

The development of flexible multifingered grippers with both adaptive grasping and in-hand manipulation capabilities remains a complex issue for human-like dexterous manipulation. After four decades of research in dexterous manipulation, many robotic hands have been developed. The development of these hands remains a key challenge, as the dexterity of robot hands is far from human capabilities. Through the evolution of robotics (from industrial and manufacturing robotics to service and collaborative robotics), the monograph details the evolution of the grasping function (from industrial grippers to dexterous robot hands) and the stakes inherent today to new robotic applications in open, dynamic environments. The aim of the monograph is to assist in the choice of a grasping and manipulation solution, taking into account both the design and control aspects, from the simplest industrial gripper to the most

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sophisticated multidigital hands. The increasing complexity of grasping function to meet flexibility challenges led to the development of control strategies based on theoretical approaches and data-based approaches using machine learning.

1

Introduction

Since the birth of the first industrial robot in the early 1960s, robotics has often replaced humans for many tedious and repetitive tasks in the industrial world. To meet these challenges, the first industrial robots were specialized machines designed according to the task. In the early 1980s, the ambition has been to make them more versatile and going so far as to equip robots with robotic hands with universal capabilities led to the development of robotic grasping research. The emergence of more agile industry and collaborative robotics requires the development of new generation grippers that are more versatile, with not only adaptive grasping capabilities but also dexterous manipulation capabilities such as those of human hands. Such objectives have motivated the development of important research activities on the design and control of robot hands.

The human hand is the effector of the upper limb. It is the "instrument of instruments," endowed with a very great functional richness due to its mechanical architecture, to its kinematics, to the large number of motor muscles, its extremely sensitive receptors, and the link it forms with the brain. The human hand has a perfectly optimized structure in relation to the different functions for which it is used.

The grasping function is one of the most complex functions to be performed by a robotic system. It requires the use of mechanical systems, adapted to the grasping of objects and to the desired actions. The integration of sensors to the gripper is necessary for multiple reasons, in particular: the localization of the object inside-hand, of the contact points and surfaces, the determination of the grasping configuration, the control of the grasping forces and more widely the control of the interactions between gripper and environment.

The grasp of parts and objects implies, depending on their nature, the implementation of adapted mechanical systems ranging from the dedicated devices to the fully actuated dexterous robot hand. The complexity of the gripper will thus increase according to the desired level of flexibility, from the grasping of objects of various shapes to their manipulation inside the gripper.

The control of these systems requires, at a low level, to ensure the control of the finger movements, the grasping of the objects and the object stability by controlling interaction forces. Implementing human hand dexterity with adaptive grasping and inside-hand capabilities requires more sophisticated controls where coordinated finger movements and interactions with the manipulated object must be managed.

To ensure more complex functions, such as inside-hand manipulation of an object with the fingertips, more sophisticated control strategies are implemented to plan and coordinate articulated fingers motions in interaction with the object. The dynamic interaction with the environment of a robot equipped with an articulated gripper, and in particular with the human, increases this complexity. Adaptation capacities and perception of the environment must then be integrated in a higher-level control able to react in real time; this control may be based on the implementation of reactive planning strategies and in particular on machine learning to take into account variability of the environment.

The grasping systems take very diverse forms, depending on the objects to be manipulated and the nature of the tasks to be performed. There can be extremely versatile systems, of anthropomorphic inspiration, offering a strong capacity of adaptation or, on the contrary, very simple specific grippers.

The definition of the grasping function (see Section 2) is linked to the level of flexibility of the task ranging from specialized grasping (i.e., grasping of a specific object) to the grasping of various objects and up to adaptive grasping and inside hand manipulation.

The monograph aims at reviewing and discussing the grasping functions from industrial specialized grippers offering a low-level flexibility, to prosthetic hand offering a mid-level of flexibility, until mutifingered dexterous robot hands offering adaptive grasping and also inside hand manipulation.

When the handling operations to be robotized are simple and repetitive, as is often the case in manufacturing production, simple symmetrical grippers are used up to specific grippers (see Section 3). It means grippers controlled in on/off mode, or even controlled, or grasping systems by adhesion using different effects: electromagnetic for ferrous materials, electrostatic for materials, electrostatic for very small objects, vacuum, etc. Gripper technologies, performances and fields of use are presented in this industrial context.

As the needs for flexibility and dexterity increase, the human hand remains a reference and represents the universal gripper in its ability to adapt to a wide variety of grasping tasks (see Section 4). This led to the development of multifingered hands with a degree of actuation and technological complexity that ranged from the adaptive grasping capability to inside hand manipulation. The development of prosthetic hands is a perfect example of the challenges involved in developing adaptive grippers and clearly illustrates the challenges of reproducing human grasp taxonomies discussed in Section 4.

To address these issues of replicating the capabilities of the human hand, we present the technologies and control strategies implemented to replicate this dexterity with multifingered hands in Section 5. The dexterity concept is introduced. Design of hands is discussed by addressing the degree of actuation, and tendon-based transmission modeling. The state of art in robot hands development illustrates clearly this key challenge: how to simplify the design while maintaining high performance level in terms of adaptive grasping and in-hand manipulation? The most advanced grippers in the field of research could not be transferred due to their excessive complexity.

The control strategy of robot hands is then addressed with a dual objective: ensure the grasp stability and achieve a defined trajectory of the object inside the hand. This strategy is based on modeling of multifingered hand, grasp quality and grasp synthesis. These approaches enable robust adaptive grasping and inside hand manipulation in known environments.

In order to take into account the variability of the environment and the adaptation of the robot hand to various objects and interaction constraints, modeling-based approaches need to be complemented by data and AI-based approaches, as discussed in Section 5.6. The question of the robustness of these approaches remains a key and open question.

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