

Design Aspects for Advanced Robot Hands: Sensory System

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1 Introduction

Dexterous manipulation requires devices provided with a suitable mechanical structure as well as an adequate sensory system. In fact, manipulating an object needs precise information about the configuration of the hand and the state of the interaction with the environment (typically the grasped object), and often the success (or simply the completion time) of the task depends on the level of this information.

Starting from the observation of the human hand, in Sec. 2 we outline the desirable features of a dexterous robot end-effector, in terms of manipulation capabilities. In Sec. 3 we inspect the sensing technologies currently available, and in particular, in Sec. 4, we focus on force and tactile sensors, which at the moment are the most debated topic in the field of sensors for robotic manipulation. In Sec. 5 and 6 we describe some tangible examples of this kind of transducers, as well as their application in dexterous manipulation in order to accomplish slip detection of grasped objects. Finally, we draw some conclusions about the choice of a suitable sensory equipment for a robot hand by means of a comparative analysis of the solutions adopted in some noticeable examples of dexterous end-effectors.

2 From human to robot hands

The human hand is the best example of dexterous end-effector we deal with and therefore it is often used as model and benchmark for robot hands. It is not an accident that the term *anthropomorphic* is so widely used in robotics. Not only the structure of the human hand but also its sensory system appears to be very effective. As a matter of fact, many researchers tend to adopt similar sensory configurations in devices, which are often quite simple from the mechanical point of view and not anthropomorphic at all; this is the case

of the ROTEX Gripper [1], whose equipment includes position, force and tactile sensors. In this sense it is possible to extend the meaning of term *anthropomorphic* to the sensory system; a dexterous manipulation device can not be considered fully anthropomorphic, despite its shape and its mechanical structure mimic the human hand, if not equipped with an adequate sensing apparatus.

The internal state of the human hand (position, velocity and force) is known by means of receptors collocated in the muscles, tendons, and joint capsule. But one of the reasons of the dexterity of our hand are cutaneous information (high-frequencies vibrations, small scale shape or pressure distribution, thermal properties). As a matter of fact, it has been shown that the lack of touch sensation, due for example to thick gloves (e.g. in space) degrades the human ability and prolongs the task completion time up to 80%, [23].

Two are the main skills of a human hand:

- *prehension*, such as the hand's ability to grasp and take hold of objects;
- *apprehension*, or the hand's ability to understand through active touch.

In this sense the human hand is both an *input* and *output* device (see [16]). As output device, it can apply forces in order to obtain stable grasps or perform some procedures of manipulation, while as input device, besides providing information about the state of the interaction with the object during the task, the hand is capable to explore an unknown environment. The same characteristics should be desirable in advanced robot hands; as a matter of fact, the application of robotic systems in unstructured servicing environments requires dexterous manipulation abilities and facilities to execute complex operations in a flexible way. Moreover, considering the possibility of

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Table of Contents Design Aspects For Advanced Robot Hands

1. Understanding the eBook Design Aspects For Advanced Robot Hands
 - The Rise of Digital Reading Design Aspects For Advanced Robot Hands
 - Advantages of eBooks Over Traditional Books
2. Identifying Design Aspects For Advanced Robot Hands
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Design Aspects For Advanced Robot Hands
 - User-Friendly Interface
4. Exploring eBook Recommendations from Design Aspects For Advanced Robot Hands
 - Personalized Recommendations
 - Design Aspects For Advanced Robot Hands User Reviews and Ratings
 - Design Aspects For Advanced Robot Hands and Bestseller Lists
5. Accessing Design Aspects For Advanced Robot Hands Free and Paid eBooks

- Design Aspects For Advanced Robot Hands Public Domain eBooks
 - Design Aspects For Advanced Robot Hands eBook Subscription Services
 - Design Aspects For Advanced Robot Hands Budget-Friendly Options
6. Navigating Design Aspects For Advanced Robot Hands eBook Formats
 - ePub, PDF, MOBI, and More
 - Design Aspects For Advanced Robot Hands Compatibility with Devices
 - Design Aspects For Advanced Robot Hands Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Design Aspects For Advanced Robot Hands
 - Highlighting and Note-Taking Design Aspects For Advanced Robot Hands
 - Interactive Elements Design Aspects For Advanced Robot Hands
 8. Staying Engaged with Design Aspects For Advanced Robot Hands
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Design Aspects For Advanced Robot Hands
 9. Balancing eBooks and Physical Books Design Aspects For Advanced Robot Hands
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Design Aspects For Advanced Robot Hands
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Design Aspects For Advanced Robot Hands
 - Setting Reading Goals Design Aspects For Advanced Robot Hands
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Design Aspects For Advanced Robot Hands
 - Fact-Checking eBook Content of Design Aspects For Advanced Robot Hands
 - Distinguishing Credible Sources
 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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