3 Kinetostatic Analysis of Robotic Fingers

in which a fundamental basis for the analysis of underactuated robotic fingers is established. A method to determine the ability of an underactuated finger to generate an external wrench onto a fixed object is presented. This method is based on the introduction of two new matrices which completely describe the relationship between the input torque of the finger actuator and the contact forces on the phalanges.

3.1 Introduction

Two main approaches dominate the literature on robotic grasping, namely, on one hand purely theoretical work on grasping and manipulation and, on the other hand, the rather intuitive design of functional prototypes. This chapter attempts to bridge this gap for the special case of underactuated fingers. Indeed, although the development of underactuated fingers aims at overcoming the theoretical difficulties of general manipulation issues and at obtaining prototypes of practical relevance, the capabilities of these fingers remain not well known. Prototypes have often been built through intuitive design, without a generic knowledge of the resulting behaviour and based mainly on special purpose computer-aided simulation. This chapter presents an effort to establish a common framework using simple theoretical bases to analyze the contact forces generated by robotic fingers during enveloping grasps. The fundamental goal of underactuation being simplicity, the objective of this work is to provide practical tools for the analysis
and comparison of underactuated fingers. Indeed, some issues have been overlooked in previous work and should be systematically addressed. For instance, the grasp force distribution, the capability of the finger to actually exert forces on a grasped object, the stability of the grasp and others will be covered in this chapter. Underactuation in robotic hands generates intriguing properties, e.g. underactuated hands cannot always ensure full whole-hand grasping. Indeed, the distribution of the forces between the different phalanges is governed by the mechanical design of the hand since only one actuator is used and some phalanges may not be able to actually exert any effort in certain configurations. This uncontrollable force distribution can also lead to unstable grasps: a continuous closing motion of the actuator tending to eject the object, as discussed in more details in Chapter 4. A new method to study the capabilities of underactuated fingers is presented that allows rigorous comparison of different transmission mechanisms through the definition of indices that are similar to the dexterity in kinematics. In this chapter:

- two matrices that completely characterize the contact forces are defined;
- using these matrices, configurations leading to stable grasps are presented;
- indices to quantify the ability of the finger to generate these stable grasps are introduced;
- different mechanisms used in underactuated hands are compared using the latter indices;

The first part of the chapter (Section 3.2) establishes the fundamental background of our analysis and requires knowledge in screw theory and mechanical transmission design. It is then demonstrated in the second part (Section 3.6), how these results can be used to characterize underactuated fingers. Throughout the first part of this chapter, linkage-driven fingers using a mechanical architecture similar to the SARAH hands are used as an example but the methodology is general and other transmission techniques are presented in Section 3.6. Also, the methodology used in the subsequent sections to develop a general static model of underactuated fingers remains valid, even if the finger is fully actuated. Hence, the title of this chapter does not contain the word “underactuated.”

### 3.2 General Static Model

The model of underactuated finger used in this book is presented in Fig. 3.1, the finger is planar (no abduction/adduction motion) and all phalanges are connected through revolute joints. Only one actuator is used to drive all the phalanges of the fingers.

Equating the input and output virtual powers of this system, one obtains

\[ \mathbf{t}^T \omega_a = \sum_{i=1}^{n} \xi_i \circ \zeta_i \]  

(3.1)

where \( \mathbf{t} \) is the input torque vector exerted by the actuator and the springs located between the phalanges, \( \omega_a \) is the corresponding joint velocity vector, \( \xi_i \).