

Chapter 1

Robotic Grasp and Workpiece-Fixture Systems

1.1 Introduction

The human hand which has the three most important functions: to explore, to restrain objects, and to manipulate objects with arbitrary shapes (relative to the wrist and to the palm) is used in a variety of ways [1]. The first function falls within the realm of haptics, an active research area in its own merits [2]. This book will not attempt an exhaustive coverage of this area. The work in robotic grasping and fixturing has tried to understand and to emulate the other two functions. The task of restraining objects sometimes is called fixturing, and the task of manipulating objects with fingers (in contrast to manipulation with the robot arm) sometimes is called dexterous manipulation.

Our fascination with constructing mechanical analogues of human hands has led us to place all sorts of hopes and expectations in robot capabilities. Probably the first occurrence of mechanical hands was in prosthetic devices to replace lost limbs. Almost without exception prosthetic hands have been designed to simply grip objects [3]. In order to investigate the mechanism and fundamentals of restraining and manipulating objects with human hands, later a variety of multifingered robot hands are developed, such as the Stanford/JPL hand [3], the Utah/MIT hand [4], and other hands. Compared to conventional parallel jaw grippers, multifingered robot hands have three potential advantages: (1) they have higher grip stability due to multi-contact points with the grasped object; (2) they can grasp objects with arbitrary shapes; (3) it is possible to impart various movements onto the grasped object. However, multifingered robot hands are still in their infancy. In order for the multifingered robot hands to possess the properties so that robots implement autonomously the tasks of grasping/fixturing in industry, it is necessary to study the planning methods and fundamentals of robotic grasping and fixturing. The objective of this book is to develop algorithms of grasping/fixturing planning and fundamentals for robotic grasping and fixturing.

1.2 Robotic Manipulation and Multifingered Robotic Hands

The vast majority of robots in operation today consist of six-jointed “arms” with simple hands or “end effectors” for grasping/fixturing objects. The applications

of robotic manipulations range from pick and place operations, to moving cameras and other inspection equipment, to performing delicate assembly tasks. They are certainly a far cry from the wonderful fancy about the stuff of early science fiction, but are useful in such diverse arenas as welding, painting, transportation of materials, assembly of printed circuit boards, and repair and inspection in hazardous environments [3, 5].

The hand or end effector is the bridge between the manipulator (arm) and the environment. The traditional mechanical hands are simple, out of anthropomorphic intent. They include grippers (either two- or three-jaw), pincers, tongs, as well as some compliance devices. Most of these end effectors are designed on an ad hoc basis to perform specific tasks with specific tools. For example, they may have suction cups for lifting glass which are not suitable for machined parts, or jaws operated by compressed air for holding metallic parts but not suitable for handling fragile plastic parts. Further, a difficulty that is commonly encountered in applications of robotic manipulations is the clumsiness of a robot equipped only with these simple hands, which is embodied in lacking of dexterity because simple grippers enable the robot to hold parts securely but they cannot manipulate the grasped object, limited number of possible grasps resulting in the need to change end effectors frequently for different tasks, and lacking of fine force control which limits assembly tasks to the most rudimentary ones [5].

Experience with manipulators has pointed to a need for hands that can adapt to a variety of grasps and augment the arm's manipulative capacity with fine position and force control. Multifingered or articulated hands with two or more powered joints appear to offer some solutions to the problem of endowing a robot with dexterity and versatility. The ability of a multifingered hand to reconfigure itself for performing a variety of different grasps for arbitrary shape objects reduces the need for changing specialized grippers. The large number of lightweight actuators associated with the degrees of freedom of the hand allows for fast, precise, and energy-efficient motions of the object held in the hand. Fine motion force control at a high bandwidth is also facilitated for similar reasons. Indeed, multifingered hands are truly anthropomorphic analogues of human hands for grasping/fixturing objects with arbitrary shapes, and implementing dexterous manipulation tasks.

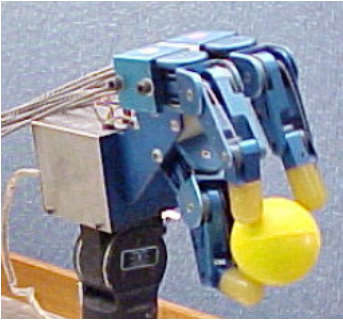


Fig. 1.1 The Stanford/JPL hand

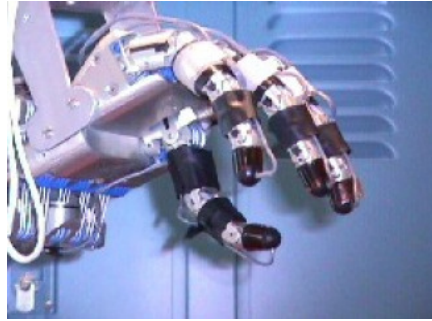


Fig. 1.2 The Utah/MIT hand

There have been many attempts to devise multifingered hands for research use, and extending our understanding of how articulated hands may be used to securely grasp objects and apply arbitrary forces and small motions to these objects. The Stanford/JPL hand (also known as the Salisbury Hand) is such a multifingered robot hand, as shown in Fig. 1.1. It is a three-fingered hand, each finger has three degrees of freedom and the joints are all cable driven. The placement of the fingers consists of one finger (thumb) opposing the other two. The Utah/MIT hand is another multifingered robot hand, as shown in Fig. 1.2. It has four fingers (three fingers and a thumb) in a very anthropomorphic configuration, each finger has four degrees of freedom and the hand is cable driven. The difference in actuation between the Salisbury Hand and the Utah/MIT hand is in how the cables (tendons) are driven: the first uses electric motors and the second pneumatic pistons.

The multifingered grasping/fixturing can be classified into two types: fingertip grasp and enveloping grasp. For the fingertip grasp, we expect the manipulation of an object to be dexterous since the active fingertip can exert an arbitrary contact force onto the object. Generally, all of contact forces can be controlled actively in fingertip grasps. Fig. 1.3 shows the fingertip grasps of a high-speed multi-fingered robotic hand [6]. The hand has three fingers, and the index finger has 2 DOF (degrees of freedom), the left thumb and right thumb have 3 DOF, so that the hand has 8 DOF total. In contrast to fingertip grasps, enveloping grasps are formed by wrapping the fingers (and the palm) around the object to be grasped. They are, similar to fixtures, almost exclusively used for restraint and for fixturing, and not for dexterous manipulation. We expect the grasp to be robust against an external disturbance. In fixtures and enveloping grasps, the number of actuators is commonly much less than the relative freedom of motion allowed by contacts between the object and links of fingers, thus, from a viewpoint of controllability, not all the contact forces are controllable actively, which is the main issue of the grasp force analyses in enveloping grasping and fixturing. Fig. 1.4 shows the enveloping grasps of the high-speed multi-fingered robotic hand [6]. In fact, this is easily seen in human

grasping where fingertips and distal phalanges are used in fingertip grasps for fine manipulation, while the inner parts of the hand (palm and proximal phalanges) are used in enveloping grasps for restraint. The so called whole arm grasps [7] and power grasps [8] belong to the enveloping grasps.

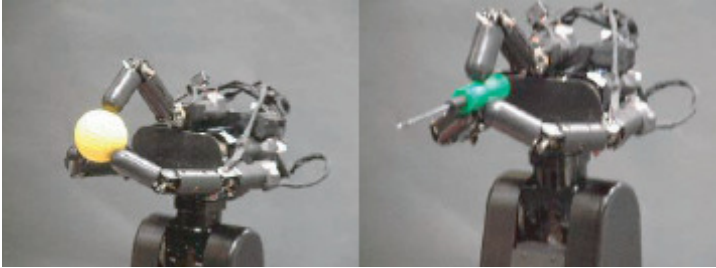


Fig. 1.3 The fingertip grasp of the high-speed multi-fingered robotic hand



Fig. 1.4 The enveloping grasp of the high-speed multi-fingered robotic hand

1.3 AMT and Fixtures

Advanced Manufacturing Technology (AMT) is a key enabler to help manufacturers meet the productivity, quality, and cost reduction demands of competitive global markets [10]. It involves new manufacturing techniques and machines combined with information technology, microelectronics, and new organizational practices in the manufacturing process. AMT is viewed as providing the basis that enables firms to exploit competitive advantages fostered by the technology. The prime motivation for installing AMT is to increase the competitiveness of the firm [11].

In view of the current trend towards advanced manufacturing techniques, such as flexible manufacturing systems (FMS) and group technology (GT), the requirement for an efficient fixture design system is becoming increasingly very important. With the aid of such a system, the process of fixture design can be automated and integrated with other manufacturing modules, which will lead to higher productivity and shorter manufacturing lead times.

Fixture is a kind of gripper used to locate and hold the workpiece with locators and clamps respectively during machining, assembling and inspection process. Fixtures can be classified into two types: dedicated and reconfigurable [8]. Dedicated fixtures generally imply that they have been designed for specific workpiece geometry. These types of fixtures are most suitable for mass production environments, where they can be discarded at the end of the production life and their costs can be absorbed by large number of products. Reconfigurable fixtures, on the other hand, are designed for a family of workpiece geometries. Pressures on the manufacturing industry during the 1980s have led to the development of many new techniques which come under the general description AMT. Automatically reconfigurable fixtures play a crucial role in these new technologies and they have been the subject of intensive research.

Although there are multifarious fixtures in industry, especially in FMS, the functions of such fixtures are equivalent to a set of contact point constraints on workpieces. For example, the locating with three plane datums is equivalent to 6 contact point constraints on the workpiece, as shown in Fig. 1.5 where the planes **A**, **B** and **C** are the so-called primary, secondary and tertiary locating datums in the 3-2-1 locating principle [12, 13], respectively. In fact, it is not easy, and not necessary to use three planes to locate a workpiece during machining, assembling and inspecting.

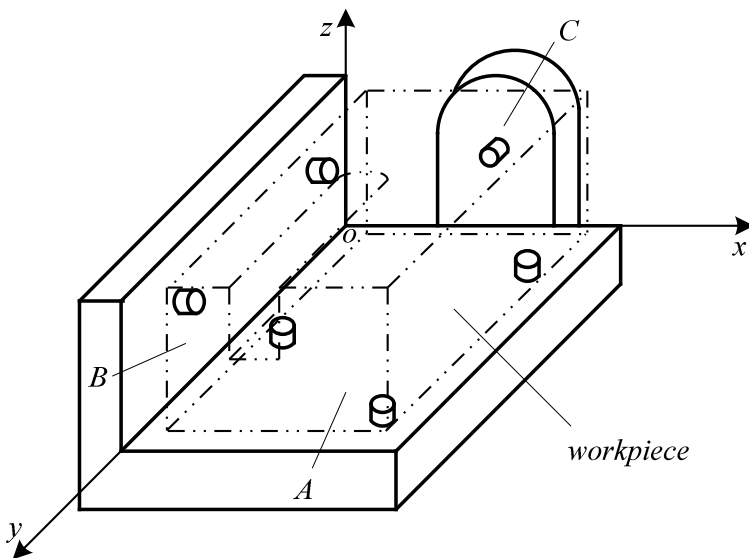



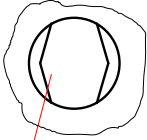
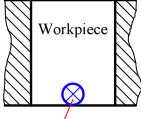

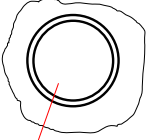

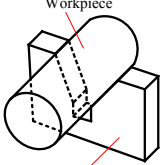
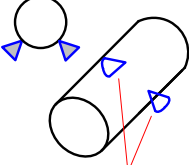
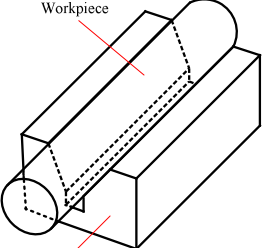
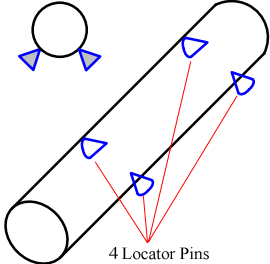
Fig. 1.5 Example of plane locators

The short diamond pins, short cylindrical pins, short V-blocks and long V-blocks are usually used to locate the workpiece in fixtures. Their functions of locating may be similarly equivalent to a set of contact point constraints on workpieces. The common locating types usually used in machining and their equivalents are shown in Table 1.1.

The fixture design process can be divided into [12, 14]:

- **fixture setup planning**, is to determine the number of setups, the orientation of workpiece in each setup, and the machining surface in each setup;
- **fixture configuration planning**, is to determine a set of locating and clamping points on workpiece surfaces such that the workpiece is completely restrained;
- **fixture construction**, is to select fixture elements, and place them into a final configuration to locate and clamp the workpiece;
- **fixture assembly**, is to assemble the fixture components in strict accordance with the previously stage. Some progress has been made towards using robots for automating assembly of the fixture.

Table 1.1 Equivalent locating

Locating Type	Equivalent Locating
 <p>Workpiece</p>  <p>Short Diamond Pin</p>	 <p>Workpiece</p> <p>1 Locator Pin</p>
 <p>Workpiece</p>  <p>Short Cylindrical Pin</p>	 <p>Workpiece</p> <p>2 Locator Pins</p>
 <p>Workpiece</p> <p>Short V-Block</p>	 <p>2 Locator Pins</p>
 <p>Workpiece</p> <p>Long V-Block</p>	 <p>4 Locator Pins</p>

1.4 Comparison between Grasping and Fixturing

The kinematics of workpiece fixturing is similar to that of object grasping. The analysis of motion and force constraints for multifingered grasps can be extended to fixtures. The goals of both fixturing and grasping are to immobilise an object kinematically by means of a suitable set of contacts. Thus the quasi-static stability and dynamic stability are important indexes to evaluate both of robotic grasping and fixturing.

Contacts can be equally treated in robotic grasping because all of fingers are active. However, locators and clamps cannot be equally treated in fixtures due to the passiveness of locators and activeness of clamps, which means that passive contact forces exist in fixtures [15]. Thus the clamping force planning in fixtures is different from the grasping force planning in robotic grasps. It should be noted that the passive contact forces exist in enveloping grasps as well [16].

In fixtures, the configuration of locators depends on the machining requirements such as under deterministic, fully deterministic and over deterministic locating. More important, the configuration of locators affects the machining quality, accessibility and detachability (namely, loading and unloading capability), and the configuration of clamps affects the fixturing closure. Locating error is related to the configuration of locators and the errors of locators, and independent of the configuration of clamps and the errors of clamps [17].

Thus, the robotic grasping mainly concerns holding feasibility, compliance and stability. In contrast, because the position and orientation precision of the workpiece to be fixtured depends on the passive locators' tolerances and configuration, fixturing for machining emphasizes on accurate localization of the workpiece besides the fixturing closure.

This book will focus on the mathematical modeling of robotic grasping and fixturing to develop methodologies for automated design of grasping and fixturing systems, so that the time spent on designing can be shortened.

1.5 Bibliography

- [1] Bicchi A. and Kumar V. Robotic Grasping and Contact: A Review. *Proceedings of IEEE International Conference on Robotics and Automation*, 1, pp. 348-353. 2000.
- [2] Klatzky R. and Lederman S. *Intelligent Exploration by the Human Hand*. Chapter 4, *Dextrous Robot Manipulation*, S.T. Venkataraman and T. Iberall, eds., Springer-Verlag, 1990.
- [3] Mason M. T. and Salisbury J. K. *Robot Hands and the Mechanics of Manipulation*. MIT Press, Cambridge, MA, USA. 1985.

- [4] Jacobsen S., Wood J., Bigger K., and Iverson E. The Utah/MIT Hand: Work in Progress. *International Journal of Robotics Research*, 4(3), pp. 21-50. 1984.
- [5] Murray R. M., Li Z. X., and Sastry S. S. *A Mathematical Introduction to Robotic Manipulation*. CRC Press, Boca Ration, Florida, USA. 1994.
- [6] Namiki A., Imai Y., Ishikawa M., and Kaneko M. Development of a High-speed Multifingered Hand System and Its Application to Catching. *Proceedings of the 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Las Vegas, Nevada, USA, pp. 2666-2671. 2003.
- [7] Salisbury J. K. Whole-arm Manipulation. *Proceedings of International Symposium on Robotics Research*, 1987.
- [8] Mirza K. and Orin D.E. Force Distribution for Power Grasp in the Digits System. *CISM-IFTToMM Symposium on Theory and Practice of Robots and Manipulators*, 1990.
- [9] Benhabib B., Chan K. C, and Dai M. Q. A Modular Programmable Fixturing System. *Transactions of ASME Journal of Engineering for Industry*, 113, pp. 93-100. 1991.
- [10] Industry Canada. (2007, July 21). *What is AMT?* from <http://strategis.ic.gc.ca/epic/site/sam-sfp.nsf/en/Home>
- [11] DeRuntz B. D. and Turner R. M. Organizational Considerations for Advanced Manufacturing Technology. *The Journal of Technology Studies*, 29(1), pp. 1-7. 2003.
- [12] Rong Y., Huang S. H., and Hou Z. *Advanced Computer-aided Fixture Design*. Elsevier Academic Press, Burlington, MA 01803, USA. 2005.
- [13] Nee A. Y. C., Whybrew K., and Senthil kumar A. *Advanced Fixture Design for FMS*. London: Springer-Verlag. 1995.
- [14] Segal L., Romanescu C., and Gojinetchi N. Methodologies for Automated Design of Modular Fixtures. *Proceedings of International Conference on Manufacturing Systems*, Iasi, Romania. pp. 151-156. 2001.
- [15] Xiong C. H., Wang M. Y., Tang Y., and Xiong Y. L. On Prediction of Passive Contact Forces of Workpiece-fixture Systems. *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture*, 219(3), pp. 309-324. 2005.
- [16] Xiong C. H., Wang M. Y., Tang Y., and Xiong Y. L. Compliant Grasping with Passive Forces. *Journal of Robotic Systems*, 22(5), pp. 271-285. 2005.

- [17] Xiong C. H., Rong Y., Tang Y., Xiong Y. L. Fixturing Model and Analysis. *International Journal of Computer Applications in Technology*, 28(1), pp. 34-45. 2007.