Chapter 3  THEORY AND BACKGROUND DETAILS

3.1  Introduction

Functionality of human hand grasping is a very complex phenomenon for study. It can handle parts / work pieces of various sizes, shapes, physical parameters and status. To imitate human hand multifinger robot hands have been developed by many researchers and scientists. A multifinger robotic gripper (MRG) is a term observed as a synonyms to robot hand / robot arm / artificial hand.....etc. MRG enables easy and skillful handling of parts / work pieces to be manipulated. It enables holding, tightening, handling and releasing and various operations which are not possible easily by conventional grippers e.g. two fingered, three fingered, vacuum type, electromagnetic type...etc.

3.1.1  Development of Gripper

While using MRG, a stable grasp can best be achieved by using a gripper with minimum three or more fingers. Majority of the research work reviews was observed to be focused for the development of three-fingered hands with or without thumb. The Belgrade / USC Hand, University of Belgrade was made by softer material such as aluminum for prototype of an underactuated self-adaptive five fingered robotic hand built in 1988. The hand has eleven DOFs and is actuated by three DC motors for closing / opening the fingers. Similarly underactuated self-adaptive robotic three fingered hand with or without biomimetic design approach has been developed by many researchers. Considering the recent development in this area we can find many innovative ideas such as

1) Ingenious designs for perfection at multiple options at object grasping
2) Use of advanced sensors for necessary feedback of gripping force
3) Vision system for feedback to obtain perfect dexterous grasping.
4) Real time control with better sensory feedback for efficient grasping

Total more than thirty existing MRG designs and most of the remaining designs are after 1996 (excluding the few notable prosthetic hand designs) suggest that development in MRG is rapid and promising from technology point of view. [Chapter 2] Though the present work has been undertaken from 2004, various designs were observed and the required design is modified while considering the recent trend in this area.
3.1.2 Tactile sensation for effective grasping

Tactile devices make direct physical contact with objects of unknown characteristics and unpredictable environments. The search for sensitive materials that can improve the performance of the grasping action are discussed in 2.3 of chapter second on Literature review. Understanding of human tactile perception has been a difficult task for emulation and developing the biomimetic action at artificial grasping.

After successful study and calibration of the variety of available / conventional tactile sensor such as Strain Gauges, Piezoelectric material (PZT ceramics), IPMC i.e. Ionic polymer material composites and pressure sensitive ink (flexiforce sensor) some relevant decisions were taken for selection and use of sensors while finalizing the design the of Fingers for the proposed MRG.

The intricate mechanics of the human hand is not the only factor behind its functional uniqueness but sensory feedback information at grasping action also offers versatility of material handling even in absences of vision system support. This led to a better grasp planning strategy with the help of sensory feedback and use of vision only for careful and skillful handling to achieve perfection at grasping.

3.1.3 Vision System feedback for dexterous grasping

From the literature review it is clear that vision systems are being used in the recent MRG systems for more effective grasp force determination and dexterous grasping. Use of vision system becomes a challenge in front of researchers, due to following complexities involved in it.

1) Selection of camera and lenses.
2) Correct Image grabbing position of camera while grasping
3) Image processing and availability of accessible data collected by the camera
4) Real time data as a feedback sensor.

All the above mentioned stages are considered for selection, installation and use of vision system as a sensor. Initial attempts for this work were with use of CCD camera, but finally a simple webcam is being used for the perfection in grasping, due to following reasons.
3.1.4 Study of Human Hand for Biomimetic Approach

Humans have a remarkable ability to grasp and manipulate objects with their hands. The high level of dexterity is achieved through complex sensorimotor mechanisms utilizing visual and tactile information and the physical structure of the hand. Dextrousness means having the skill to handle the object without damaging it.

Utilizing these abilities, humans can modulate grasp forces, precisely position objects, and detect fine surface features. Consider how easily one can screw in a electric lamp (i.e. glass bulbs). This action requires a delicate grasp to prevent breakage, in addition to careful control over insertion force and position to engage the threads.

Humans are also capable of readily dealing with environmental uncertainty or adapting to environmental changes. In some situations robots are more aptly suited than their human counterparts. For example, robots used in automobile factories can assemble components with greater speed, accuracy, and endurance than a human worker. Robots can also be used in environments that are hazardous or dangerous for humans (e.g., radioactive sites) or difficult to access (e.g., deep underwater or in space) or not at human scale (e.g., microsurgery). Today, autonomous robot operations are used only when the environment is highly structured (e.g. factory automation).

By studying the various task statements and applications it is decided to adopt following procedure at the stage of synthesis.

1) Appropriate Posture for reaching to the object
2) Grasp points in group of physical contacts
3) Estimation of grasp force with sensory feedback
4) Actual holding and lifting of the object

Thus biomimetic approach can be embedded in designing the MRG systems. Selection of actuators, size of hand, selection of sensors and their role in deciding the control action …etc are directly influenced by the Biomimetic approach.
3.1.5 Under-actuated Robot gripper for Dexterous grasping

The term “underactuated robotic hand” means the numbers of actuators present are less than the robot hand's degrees of freedom (DOFs). The artificial intelligence embedded into the design of the hand must allow the automatic shape adaptation of the fingers and subsequently the minimum force application at grasping operation.

For this “underactuated robotic hand” a similar term “degree of mobility” can also become suitable match in context with planer moment of the concerned elements. But consecutive movements of the various linkages due to sole actuator are considered in various research work. Hence joint movements must have been considered as different axis in 2D plane of each joint of a finger.

Each finger of human hand has three joints hence three degrees of freedom. Thumb has two joints i.e. two degrees of freedom. Thus, there are total 14 degrees of freedom for four fingers with one thumb. Movements like abduction and adduction are sometimes considered for few grippers. As per the problem statement, simplification of task and optimization of the design; it has been decided to design only three finger with thumb. Thumb at opposite side for grasping with the counterpart finger i.e. middle finger actively participates for biomimetic action of the MRG.

The links provide the actuation to the successive joints. Therefore, separate actuation is not required at each joint. In the proposed mechanism of this research, the links moves inside the grooves cut in the phalanges, thus providing limits to the motion of the gripper. This mechanism is explained in the chapter 4 while discussing the gripper design.

The MRG designed in this work is for performing cylindrical, spherical, and planar grasps with both power and precision grips. In a precision grip, the object enters into contact only with the distal phalanxes, which automatically stay parallel to the axis of the hand. When two of the fingers are facing each other, the third finger is blocked and the hand acts as a precision gripper. Remaining two fingers are meant for the support to the object / workpiece at variable orientation in dynamic performance of the gripper.
3.2 Anatomical study for Bio-Mimetic Grasping

In case of Industrial Robots, the process in which a desired object is gripped by the fingers of a multi-fingered hand can be referred as a grasping. Various Grasps by human hand can be categorized into three general groups: precision grasps, power grasps and partial grasps. Anatomical study is essential to adopt human grasping strategy at artificial grasping by the MRG. The Precision grasps grip an object with the fingertips. The way a chopping stick or pen is held for writing is one example of a precision grasp. For dexterous grasping this orientation of gripper with proper estimated grasping will offer effective biomimetic action.

![Diagram of Grasps](image)

Fig. 3.1 Types of Grasps classified as per the orientations of the human finger. [107]
The precision grasping has a high degree of manipulability; it does not have a large capability to resist loads. The grasps for screw tightening, banging of a hammer or holding for wrenches are the examples of a power grasp.

Partial grasps do not totally constrain the movement of the grasped object. They are used to perform tasks on objects whose motion is limited in other ways. One example of a partial grasp is the hooked fingers used to open a drawer with recessed handles. It would seem that the type of grasp is aligned with the task involved – precision grasps for manipulation and power grasps for resisting forces. There are situations, however, where force must be applied to the object but physical obstacles prevent a power grasp. One example of this type of situation is the removal of a tool from its retaining clips in a toolkit. The fingers cannot encircle the tool since it is mounted on a surface, so a precision grasp must be used to extract it.

The process of obtaining a precision grasp as per human normal action can be separated into following four stages for better design of MRG:

1. Object data acquisition – determining position of the target object.
2. Grasp sensor and control synthesis – determining the appropriate hand position and configuration for type of object and task.
3. Approach position – positioning the hand near the object.
4. Grasping operation – obtaining the actual grasp of the object.

Fine force transmission on the object simply by moving the finger is expected in each type. For variety of the objects the fingers encloses an object. There are multiple contacts on each finger and opposing thumb contact is usually involved. There is no ability to manipulate the object within the designed MRG hand but the ability to resist forces on the object is greatly enhanced. Hence for the decided task statement precision grasp is expected and hence designed accordingly.

3.2.1 The Anatomic Frame: Finger Bones and Articulations

An understanding of the skeletal and joint structures of the human hand is a starting point for the development of a mechanical general purpose manipulator. Though there is still much to be known about the hand’s functional parameters, the topography of its bones
has long been determined. Figure 3.2 shows the bones and joints of a human digit from two different perspectives.

Each of the four fingers comprises 3 of the 27 bones of the human hand: proximal, middle, & distal Phalanges, extending from the palm outward. First two of these segments are considered i.e. long bones, having tapered shafts that are concave in front, convex in back and convex from side to side. The distal, phalanx is small & convex on its dorsal side. Its flat palm surface presents a roughened horseshoe elevation which supports the pulp of the fingertip. Joint angulation is expressed by movement of these bones along the articulated surfaces of each other. Details of Bones and joints of the human index finger:-

Fig. 3.2 (a) Palmar (b) lateral views of the bones & joints of human index Finger.[123 ]

Fig. 3.3 Orientation, surface, and finger motion terminology. Abduction / adduction arrows corresponding to index finger motion[123]

Fig. 3.4 Scope of motion corresponding to finger orientation.[123]
Special care was taken in the design of the linkages to replicate the basic geometry of the corresponding human finger bones. This was for functional purposes and to give the artificial finger an appropriate aesthetic when covered by the tactile skin.

The robot, like its human counterpart, can consist of three segments: proximal, middle, and distal. Their link lengths and widths are extrapolated from external anthropometric hand data for a 1.5 percentile natural human hand dimensions. However some size adaptations were made, to allow for incorporation of bearings and mechanical stops at the joints. In future versions of the robot, we may investigate other techniques for modeling finger link lengths.

3.3 Material handling by Robotic Grippers in industries

A robot arm by itself can not serve for grasp purpose until a load or a tool is suspended form or attached to it. Devices connected between the robot wrist and the load for grasping the object provides the capacity to do a wide variety of manipulative assignments. For the study of gripper force calculations and its relation with the size of fingers and size, shape & weight of the object to be grasped various Industrial gripper supplier do offer their expertise.

The main function of a gripper is to grasp and to release work pieces during the material transfer route. Generally the gripper for industrial robots is a specialized device that is used to handle only one or a few objects of similar shape, size and weight in a repetitive and is limited in its versatility.
For obtaining the generalized solution for grasping a class of universal gripper is expected. This class consists of inflatable fingers, soft fingers, and multi-fingered grippers and grippers of special types. Many newer innovative designs are appearing in this category for various applications.

a) Inflatable / balloon / bellow type grippers - The inflatable gripper offers a solution for picking up irregular shaped objects for unbalanced loading. It is also useful for gripping fragile, delicate and glass like objects with thin walls. The inflatable gripper actuated by pneumatic system made of flexible material e.g. high strength rubber can hold previously noted delicate objects.

b) Soft Grippers - A soft gripper mechanisms consists of multi links and a number of contact points actuated by various basic drives. The soft gripper can actively conform to the periphery of objects of any shape and hold them with uniform pressure. (e.g. gripping by octa-arm, foam type friction pads.

c) Moldable grippers - For general economical and easily controllable gripper devices, moldable polymer materials possessing high strength silicon rubber, polyurethane, epoxy etc. can be used for making of gripper. These can produce functional grippers which can be quickly made for a variety of entirely different and specific grasping of unique objects.

d) Multi fingered Gripper - The clamping movement of 2 or more than 2 fingered type grippers normally offers the entire possible human like movement e.g. polar gripping movement, lateral gripping movement, .... etc. Based on the anthropomorphic hand model the 3 finger device are proposed by many researchers which has the ability to pick up an object such as a hand tool, complex shaped objects, semisolid object....etc. with a firm encircling grasp while exerting the force or torque.

Though it seems that the maximum types are covered in the above discussions more innovative types for unique operations may still remain uncovered as a specific application oriented designs of miscellaneous type.

Brief theory related to multifingered robot gripper, from anatomical and industrial view point is discussed in this chapter. In a further stage, selection of the actuators, sensors and necessary control system is discussed in the next topic.