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Automatic Grasping Techniques Used in Robot or Automatic Machine to Grasp Intricate Solid Object

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Abstract

The grasping of the object in robot hand or any other automatic grasping mechanism is a complex task. Several constraints are involved in grasping. Taxonomy of human grasp helps to identify the type of grasp used for particular requirement and design of robot hand or automatic grasping mechanism.

The robot without memory, computational ability and some intelligence is simply a machine. This paper deals with only gripping aspect of robotics, which can be used as tool for designing computer program for controlling robot hand.

The equilibrium conditions, coulombs law of friction model should be satisfied for stable grasp. The essential conditions of object which makes it possible to grasp, "graspability" is discussed. The strategies should be followed to find out optimal gripping positions satisfying all the constraints. The conditions for reorientation and regrasping of the object and computation of force (torque) required to avoid slippage is discussed.

Introduction

Robot is a machine developed to provide capability of human being. Even if the Robots are developed in terms of attributes similar to human attributes (i.e. intelligence, memory, all types of senses) but it will not be useful without hand. Similarly there are some other automatic machine tools where automatic grasping is essential. The reason for grasping the object is not only to gain the complete control over its position but the grasp should also be able to orient the object to do specific task. The task requirement and job geometry dictates grasp choice, which also is clear from every day task. The grasp used for picking up a pencil is entirely different from the one used for writing, though the object geometry remain same.

Whatever is the state of automation, unfortunately, the adaptability of human hand have been difficult to duplicate. It justifies the dominance of human hand for many type of applications. One of such example is grinding of precious stones used for jewellery. The design of jewellery has become automatic by using computers, if it is interfaced with manufacturing, the cost of production decreases and quality improves.

The programmer for the robot does not have only challenge of writing the program which can do the specified job but the program should be efficient to run it in real time system. Minimum of 6 parameters are required to define location and orientation of any point in robotics system. For a robot to complete the task several such points have to be defined if robot is following some specific path. Besides location and orientation, several other parameters have to be defined depending upon the nature of task. Hence optimisation of the memory space is another challenge for the programmer. Hence only the use of computer in robotics system for automation is not the success, but efficient utilisation of the computer is essential for improving productivity.

Human grasping

Dexterity and prosthetics are the main requirement of Robot hand. Human hands have numerous degree of freedom which is quite difficult to duplicate by man made Robot hand. Though multi-fingered Robot hands provide multi-degree freedom, tactile sensing and controlling these multi-fingered hands are another challenge to correlate these artificial hands with human hand. Because of the complexity of the grasp, the study and comparison of analytic grasp models with the processes that people use in choosing grasp and manipulating objects in particular environment is important. Human grasp can be used to identify the nature of grasp for different types of task requirement and object geometry. But conclusions can not be drawn from human hand, because the human hand are evolved from millions of year and human hands are not absolute for many industrial applications.

The human grasping can be classified and codified depending upon task requirement and object geometry. The comparison and analysis of grasp by human hand helps for designing Robot hand that is better than human hand.

Classification of human grasp

The most common method of classifying human grasp is according to shape of the object to be grasped. They are cylindrical, fingertip, hook, Palmer, spherical. But these classification do not always represent the state clearly because, even during the course of single task with single object, the hand adopts different grips to changing force/torque conditions. The example can be opening of the cap of the bottle, where hand adopts different grips to adjust to changing force/ torque conditions. Hence the grasp can be categorised according to the function instead of appearance.

Another way of classifying human grasp is to divide it in to two broad categories i.e. power grasp and precision grasp. Where security and stability is required, power grasp is used. Power grasp requires large area of contact between grasped object and the surface of the finger and palm. Where sensitivity and dexterity is required, a precision grasp is chosen. The object is held between fingers and thumb in the precision grasp.

The hierarchical tree of the grasp developed by Cutkosk (1989) is very useful in classifying human grasp. This taxonomy of human grasp is very useful in the design of grasping mechanism, since it allows one to see very quickly where a set of grasp lies in the space of all possible grasps.

Definition of grasp

The grasp in the context of Robot is gripping or holding the object without any motion between object and gripper. In this way the meaning of grasp differ with the grip, whose sole purpose is only to hold or clamp the work-piece to transfer from one place to another. The grasping is advanced form of holding which can pick up and manipulate the object to accomplish complicated work, satisfying all the requirement of the good gripper.

The Robot hand to have dextrous capability, should be able to grasp the object which prevents them from slipping from grasp, reorient and regrasp the object within the hand. When the shape, location and orientation of the object is known, it might be easy to grasp the object perfectly. But when these information are not available, it is useful to develop grasping strategies that rely on local feedback, object shape constraints, and friction forces to ensure variable grasp. Hence if the conditions can be developed for stale grasping in terms of mathematical models, the control, sensing and co-operation among fingers are possible.

Condition of stable grasping

The slippage can occur between the object and the gripper because of weight of the object, moment due to holding the object eccentrically, inertia of the body or any external force in the body.

Fearing (1986) suggested three necessary conditions for stable grasp. The first condition is about the equilibrium of the object, second condition is about relation of forces with friction and third condition is possibility to increase magnitude of force.

First condition: The most important and primary condition for stable grasp is that the object must be in equilibrium. The net force or moment acting on a body is balanced by each other.

Second Condition: All the forces in friction type gripper must be with in the friction cone so that there will be no slip at fingers. According to Columb's model of friction, for a point in contact with a planar surface, the tangential force is a linear function of a normal force. The friction angle $\phi = \tan^{-1} \mu$ is half the angle of infinite length cone, orthogonal to surface. This cone is known as friction cone and the contact forces directed outside the cone will result in slip at contact point. Referring fig 1, if FN is the force component normal to the surface, Ft is the tangential component and α is the angle of force with respect to the surface normal, then the grasp is stable.

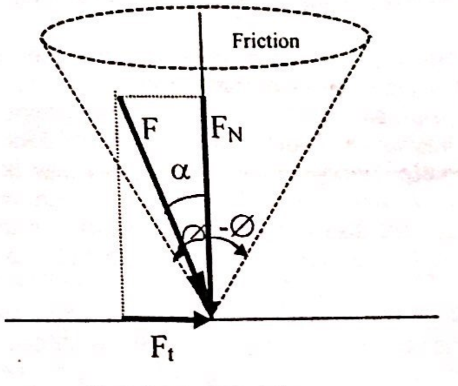


Fig 1: Friction Principle

Third condition: The final condition for the stability is that it should be possible to increase the magnitude of the grasping force to prevent any displacement due to an arbitrary applied force. To restrict the motion of a rigid planar body, four frictionless point contact are required. Since a point contact with friction, can apply forces in more than one direction, only two fingers with friction are sufficient for stable grasp. When applied force is larger than the friction force, it is necessary to increase the normal force at each finger to prevent displacement of object.

Graspability

The forces of two fingered gripper must be collinear, of equal magnitude and opposite in sign to held the object in equilibrium condition. The forces between two fingers are not independent and are related by angle between the surfaces on which the fingers are acting.

Considering the portion of the polygon with angle (at vertex is grasped by two fingered gripper as shown in fig 2. The angles are defined as in fig 1. The second condition of the stable grasp says that the force angles must be within the friction cone. Hence $\phi > \alpha_1 > -\phi$ and $\phi > \alpha_2 > -\phi$

The force angles are measured in the counter clockwise sense from the surface normal. From Fig 2,

$$\alpha_1 = \alpha_2 + \psi$$

For stable grasp, the maximum value of force angle is equal to friction angle. Hence,

$$/\psi/ < 2\ /\phi/$$
$$/\psi/ < 2\ /\ \tan^{-1}\mu/$$

Hence the condition for stable grasp is;

$$\tan\ /\psi/2/=\mu$$

This condition indicates that if sides are closed to parallel the co-efficient of friction required to grasp the object is small.

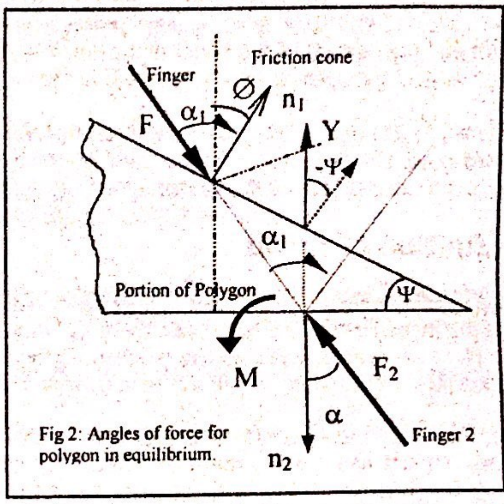


Fig 2: Angles of force for polygon in equilibrium.

For $\psi = 0^0$ $\mu=0$ i.e theoretically the object with parallel face can be grasped even by two friction less fingers.

For $\psi = 90^0$ $\mu=1$ i.e to grasp the object by two fingers at sides perpendicular to each other maximum co-efficient of friction is required.

For $\psi > 90^0$ $\mu>1$ i.e the condition do not exist. Hence it is not possible to grasp the object in the sides where angles subscribed by these sides are more than 90^0.

Phases of grasping

Grasping consist of several phases or stages. It starts with planning phase taking all the environment in to consideration and leads to stable grasp. Buss (1996) divided grasping phases as planning and holding phases. Fearing (1986) has divided the grasping in to four phases as approach phase, initial touch phase, initial grasp phase and stable grasp phase (Fig 3).

The important component of task planning for gripper is to determine grip positions. Grip position determination requires considerations of many issues such as condition of stable grasp, geometry of object, environment, surrounding obstacles. All these attributes have to be analysed in planning phase of grasp. Many acceptable grips may be possible, but there must be some criteria to select most appropriate grip. Distance from the centre of mass, contact area, possibility of slippage, force to be applied for stable grasp have to be determined and all the values of these attributes might change with respect to time. If the robot has efficient computational facility, the optimum grasp can be planned to meet all the requirements.

Holding phase is the one in which the object is grasped stable. The fingers apply optimum contact forces at designed positions and external forces are counter balanced. The force acting on the gripper may vary as stated in third condition of stable grasp. Hence on-line computation may be necessary to vary the forces in fingers to prevent displacement of the object due to arbitrary applied force at any instant of time.

Approach phase: Any type of objects can be described in several discrete regular geometrical form. If the object is laying on the plane, 3 degree of freedom of the object will be lost and hence it will introduce many constraints to approach the object. The visual sensor can be used to identify the location and the shape of the object such that finger orientation can be decided.

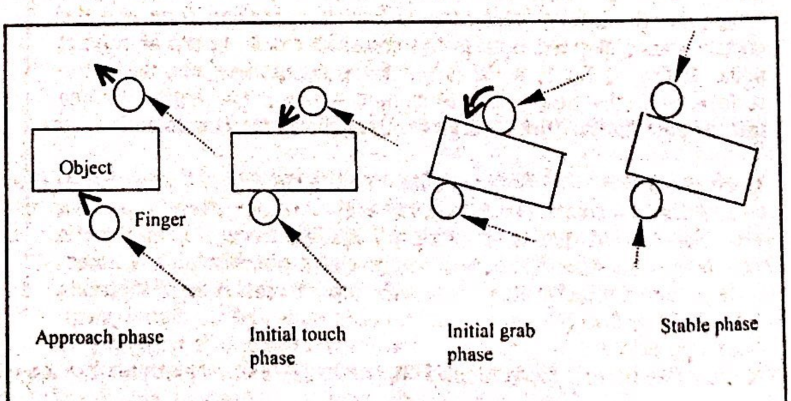


Fig 3: Phases of two finger stable grasping.

Initial touch phase: The condition when any one of the finger senses the contact is initial touch phase. But this local contact will not give complete information of the orientation of the object. If the object moves when touched, multiple contact can detect the direction of the motion. The rotation centre indicates where the bulk of object is, so that the other finger can successfully grab it. During the approach phase and initial grab phase, it is important to have low stiffness and velocity of the fingers to prevent parts from flying away from finger due to impact.

Initial grab phase: When two fingers successfully intercept the object, the fingers starts applying force. Due to this the object may translate or rotate, if the force applied is not collinear and opposite.

Stable grasp phase: To achieve the stable grasp the conditions of stable grasp must be satisfied. The reorientation and repositioning the fingers may be necessary for the optimal gripping position.

Gripping Positions

Walter (1985) studied the problems of automatically determining gripping positions for two finger gripper based upon geometrical knowledge of the object and its environment.

When a polyhedral part is gripped by a parallel finger gripper, the grip pose in part co-ordinate system is given by tuple (g, va, vo). Where g is position vector, va is unit approach vector parallel to the axis of the finger and vo is the unit orientation vector perpendicular to the pads of the finger. The fast computation is important so that the algorithm can be used in real time system. The information can be collected from the feedback system or from the sensors installed in the gripper. If there is a prior knowledge of information, the computations can be done off line.

The set of possible grip positions can be generated which satisfies the condition for stable grasp. The optimum tuple can be determined and others can be discarded. Following strategies can be used for determining grip position.

1. Determine set of grip position for the part.

1.1 Select pair of grip positions for the part.
   * nearly parallel and opposite to each other
   * separated by less than maximum opening of hand, each such pair determines orientation vector vo

1.2 For each set of selected surface generate a finite set of possible approach vector, va.

1.3 Check for the interference between finger and object, discard those that fail. For each feasible vectors choose a possible grip g, close to centre of mass.

2. Evaluate these feasible grips according to slippage and twisting criteria. Discard those falling below some set of threshold value. Rank them according to combination of these criteria.

3. Beginning with the highest ranked grip, check for the interference with the obstacle in its approach and select the grip which satisfies all constraints.

The problem of choosing a grasp based on analytic grasp models, quality measures, and constraints are illustrated in Fig. 4.

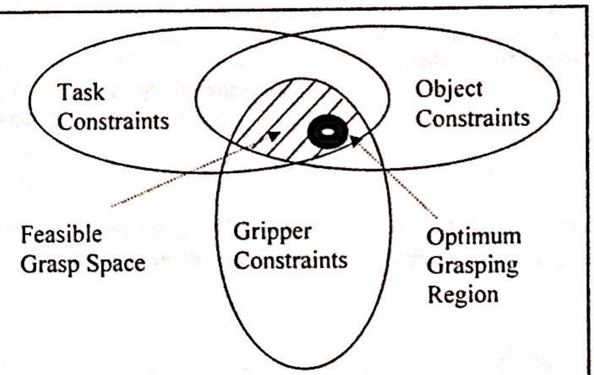
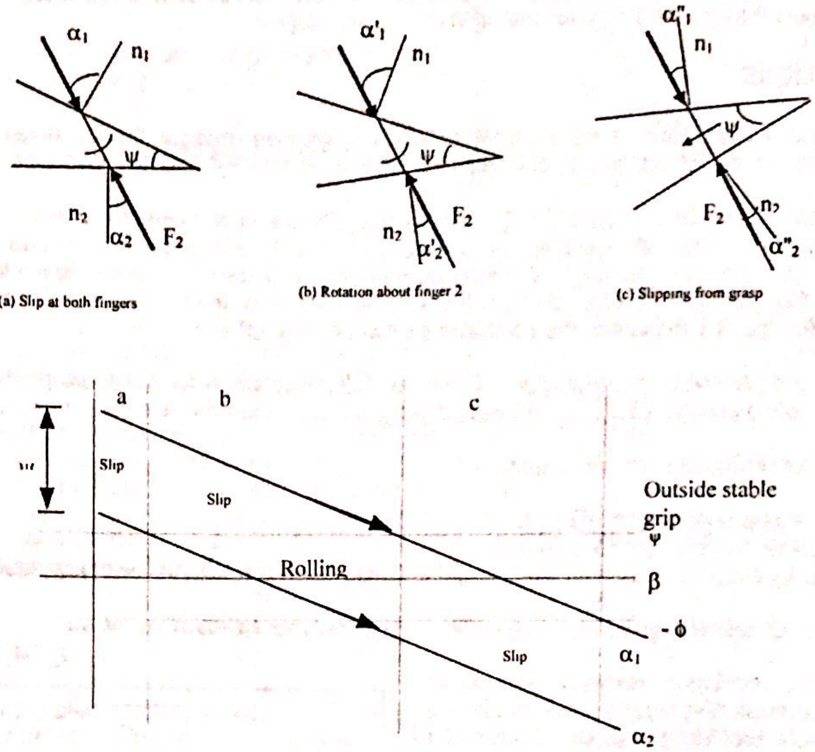


Fig. 4: Optimum grasping and constraints

Manipulation with dextrous hand

The manipulation is complex task in robot hand. Fig. 5 represent one form of modelling of two fingered hand where several issues are involved in analytical modelling of grasping and manipulation. In actual practice there are non-linearity in the contact conditions between soft finger pads and grasped object and in drive train or actuator mechanism. Fearing (1986) considered the static condition of two fingered gripper and assumed that finger force are much more than inertia force and frictional force. Assuming one finger as fixed, Fearing developed the equation for the finger force at another finger to achieve stable grasp.

Fig. 6 graphically describes the behaviour of the force angles with respect to friction angle for the object shown in fig 2 and is rotated by angle β. The figure shows the initial conditions of the finger 1 outside the friction limit, and finger 2 within. The rotation of the object occur until the force angle for finger 1 gets inside the friction cone. Fig.7 also explains the limit on the vortex angles or graspability. In figure (a) both the fingers are outside the friction cone, hence there is a slip at both the fingers. Finger 2 will be with in the friction cone in figure (b) but the rolling is still continuing. The object is rotating counter clockwise due to moment. By the time the force of finger 1 reach with in friction cone, force of finger 2 will be out, hence starts slipping. In this way the limit of vertex angle for fixed friction angle can be illustrated.



(a) Slip at both fingers (b) Rotation about finger 2 (c) Slipping from grasp

(d) Graphical representation of cases a, b and c.

Fig 5: Ungraspable object.

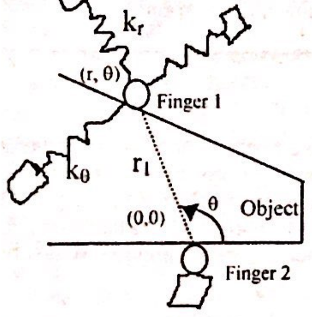


Fig. 6: Polar stiffness representation.

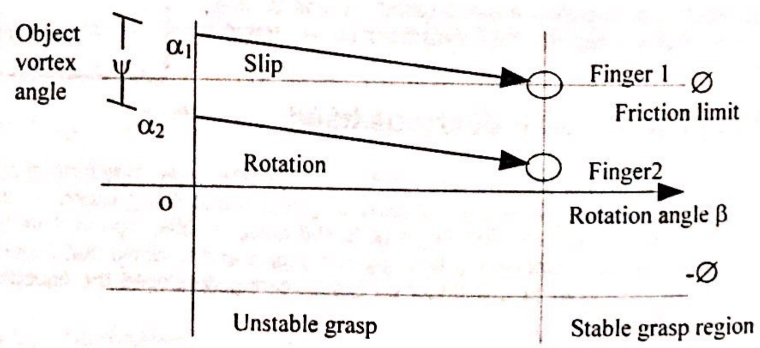


Fig 7: Graphical representation of force angle and behaviour of grasp

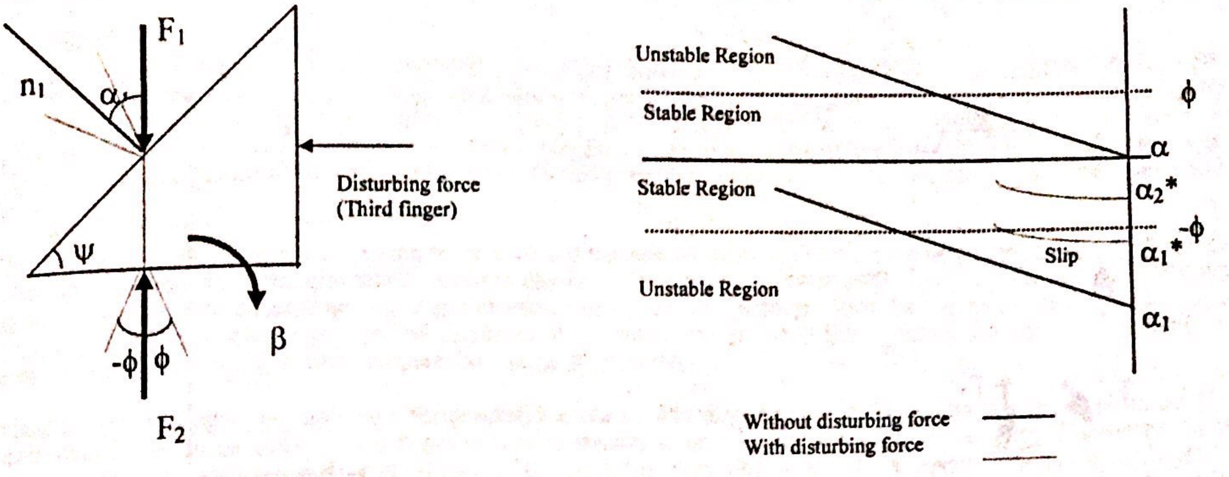


Fig 8: Making stable grasp with third finger.

Reorientation/Regrasping of object

When any type of disturbance force is added in the object with stable grip, the object will loose its stability. If the object does not slip out of hand and if the angles of friction force is with in the friction angle, the object can be regrasped.

Fearing (1986) considered force and moment balance and computed the ratio of tangential to normal force due to disturbing force for both the fingers. These two equations for two fingers can be used to predict the behaviour of the grasp and can also be used to find out how much rotation can be given to reorient the object. The ratio of tangential to normal force component gives the angle of the reaction forces of fingers with respect to surface normal.

The disturbing force can also be used to bring finger force back with in friction cone. Fig 8 shows how third finger can be used to grasp an object that can not be grasped with two fingers. The third finger can be applied at wide range of locations, directions and magnitude. If the third finger control the amount of rotation, manipulation or reorientation within the hand is possible. The entire process is explained in fig 9. The process can be repeated infinitely if rotation without slip about the fixed finger is ensured.

Computational Models for Grasping

Three type of motion are possible between object and gripper. These slippage are translation, rotational and twisting. The modelling and predicting a contact force at each finger tip is necessary to co-ordinate the motion of fingers of a mechanical hand.

Translation Slippage
This is a translational movement of the object in the direction of force. The translation force required to cause slippage of a part in a hand depends on force applied by the fingers, external force acting on object and coefficient of friction. Abel (1985) analysed the frictional forces required to held the object without slippage in a planar grasp. He developed the compatibility condition that relates object shape, contact locations and surface roughness as characterised by coefficient of friction.

Holzmann(1985), presented a procedure of computing friction forces required to satisfy static equilibrium, when the set of normal forces exerted by three fingered mechanical hand is known. Kumar (1989) developed the method to determine the distribution of forces between the multifingered grippers. The optimum solution for gripper problem is used to control gripper. But time spent for computing optimal result plays vital role in on-line control. Kumar proposed fast and efficient sub-optimal method for computing gripping force.

Rotational Slippage
If the force acting on the object and force applied by grippers are eccentric, then rotaional slippage is caused. Rotational slippage depends upon the torque and pressure applied on a part, shape of contact and coefficient of friction. The torque due to external force can be equated with the frictional torque of gripper and hence the force required to resist rotational slippage can be computed.

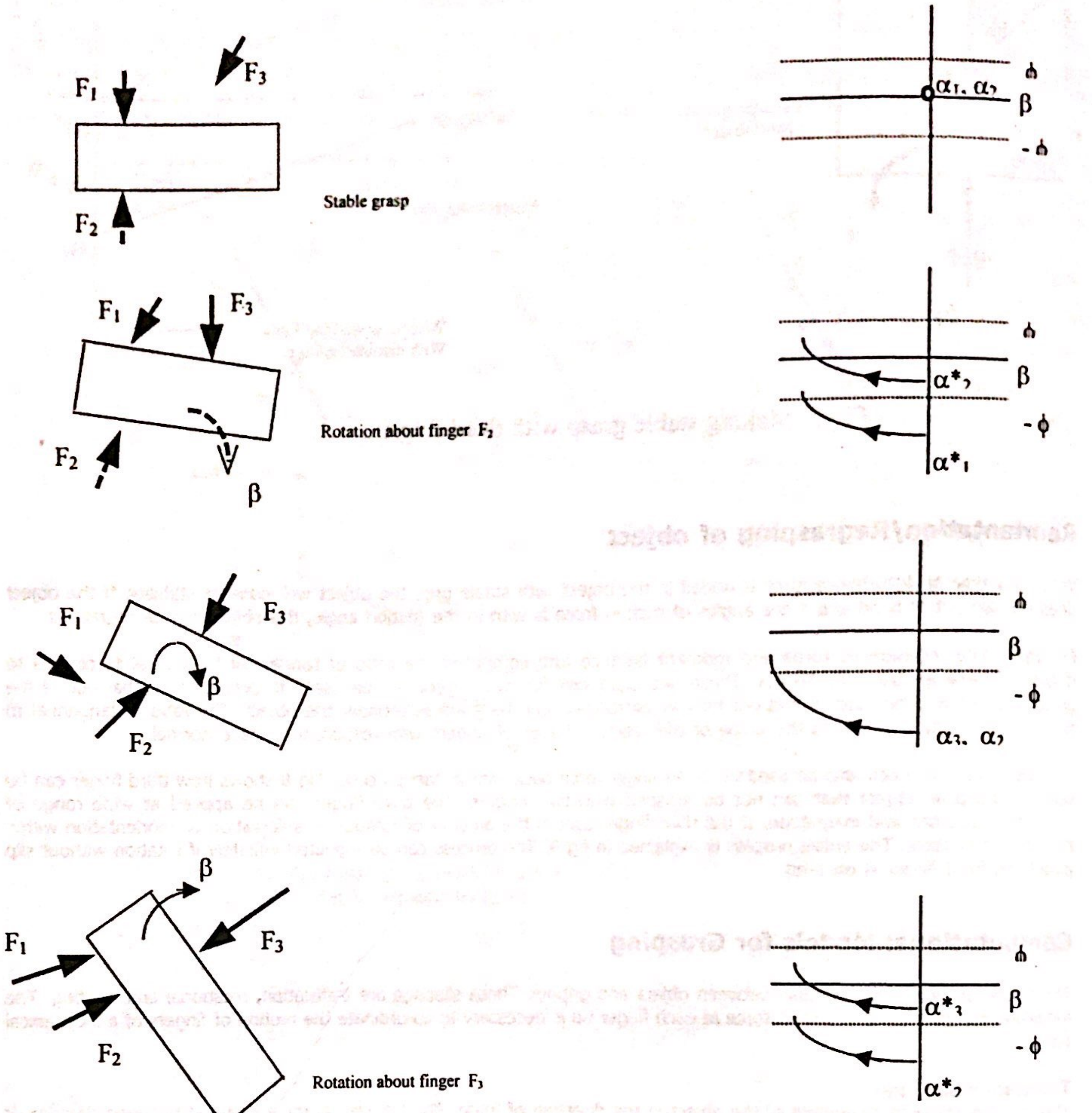


Figure 9: Making stable grasp with third finger.

Twisting

Twisting of object in the gripper is due to acceleration torque or misalignment of gripper during approach to the object. One relevant measure of twist is the distance by which the fingers must be separated for the part to come out of position. At each contact point of the object and finger, friction cone is drawn. If two contact point exist such that the open line segment joining them lies in both contact friction cone, then there will not be any twisting.

Conclusion

The grasping is a method of holding the object without any motion between object and gripper. It is different from simple gripping or holding the object. Grasping is important in manufacturing and many other industrial processes. The grasping too should be automatic for the automatic manufacturing systems or in Robot. Though grasping seems to be simple phenomenon, the automatic grasping is a complex process and several conditions are associated in it. The taxonomy of human grasp help to correlate the attribute of the human grasp for manufacturing task and can be used to design Robot hand.

The stable grasp should satisfy the condition of force and moment equilibrium, Columb's law of friction and variable force for changing requirement. The graspability is the ability of the finger gripper to grasp the object of given shape. Various gripping positions are possible for the object of known geometry. The strategy should be followed to select the optimum gripping position, which satisfies all the requirements of stable grasping and this selection procedure is completed in minimum possible time such that computation can be done on-line.

Minimum of two fingers are necessary for gripping the object. Additional force may disturb the stability of grasp, but this disturbing force can be used as third finger to provide stability to unstable grasp or reorient the grasp. There are need of efficient, accurate and fast mathematical models for computing forces to be exerted by fingers and the angle turned to reorient the object which satisfies all the constraints of grasping system. Knowledge based system or expert system can be developed to select the optimum gripping position for different geometrical shape. These system can be used to grasp the intricate shapes during manufacturing or manipulating during manufacturing.

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Author's Biography

Bhola Thapa is working with Department of Mechanical Engineering, Kathmandu University as an Assistant Professor. He received his M. E. (Mechanical) from Birla Institute of Technology and Science, Pilani, India in 1999 and B. E. (Mechanical) from Punjab Engineering College, Chandigargh, India in 1991. He won several scholarships like Education Medal from Ministry of Education in 1998, Fellowship under the Netherlands Fellowship Programme was awarded by the Kingdom of the Netherlands for participating in the Maintenance Course organized by IITM, Enschede, the Netherlands, under the recommendation of H.M.G. Nepal in the year 1993, and Colombo Plan Scholarship awarded for four year by Government of India under the recommendation of Ministry of education, H.M.G., Nepal in 1986. He has been trained in different countries and some publication to his credit.