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Force Closure Analysis of Robotic hand using Matlab

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Abstract: Robot has the capability to manipulate the objects to have stable grasp. It should be prepared to grasp new objects according to shape and size. Grasp must be compatible with task requirements. Stable grasp requires stable force closure analysis, keeping human hand anatomy in mind. The trajectory of thumb and finger is designed in matlab using applied force by fingers. Further force applied by fingers on point of contact to have stable grasp is calculated to reduce the complexity of grasping.

Keywords:- Robotics, multi-finger robots, force analysis, matlab, robotic hand

I. INTRODUCTION

ROBOTS are now widely used in many industries due to the high level of performance and reliability. The development of powerful computational platforms for simulating the behavior of robotics systems constitutes a fundamental tool for designers, users, and researchers of this field. These simulation platforms are very important for robotic manipulation because they enable the computation of the robot's trajectories which are required for grasping objects in the environment. For Industrial purpose the robots are being used for welding, assembling etc. while for Domestic purposes it is used for pool cleaning, domestic vacuum cleaning etc. the robots apart from these it is being used in military, in robot assisted surgery etc. Thus we can say that in future its demand is going to be very high. But with demand, there will be demand of intelligent robots i.e., the robots that can perform the entire task like human being. For this one of the important properties that are required is the grasping capability of the Robots. Hence grasping has become an important field of robotic research. Simple grippers and task oriented end effectors are being generally used in various applications. But for this kind of end effector the area of application is very less. Hence dexterous multi-fingered hands represent an interesting research area. Two of the major issues in the area are; design of more dexterous hand, and its grasp capability including quality of grasp. Robotic assembly and welding operations demand more dexterous and compliant devices to overcome the complications demanded by the desired motion and object manipulation.

II. GRASPING THEORY

A. Basic Definition

We define grasp as a set of contacts on the surface of object. The forces or torques that is applied on the object by robotic hand depends on the configuration and the contact model of the hand. Always we consider the point contact model i.e. the finger tips are in contact. Once the contact model is selected one can now choose the closure properties of grasp that is required. Generally the contact between the finger and object is idealized as a point contact at some fixed location. By idealizing this condition one can ignore the possibility that the fingers are sliding or rolling on the surface of the object.

A force applied by each finger on the object is a grasp force f_i . In the case of a frictionless contact type, the grasp force acts along the contact normal. If not then the grasp force f_i must satisfy coulomb's law, to ensure no slipping at the contact

$$\sqrt{f_{ix}^2 + f_{iy}^2} \leq \mu f_{iz}$$

Where (f_{ix}, f_{iy}, f_{iz}) denotes x, y, z components of the grasp force f_i in the object coordinate frame and μ the friction coefficient.

B. Wrench

A wrench, w_i , is the combination of both, the force and the torque or moment, corresponding to the grasp force f_i .

$$w_i = \begin{pmatrix} f_i \\ \tau_i \end{pmatrix} = \begin{pmatrix} f_i \\ r_i \times f_i \end{pmatrix}$$

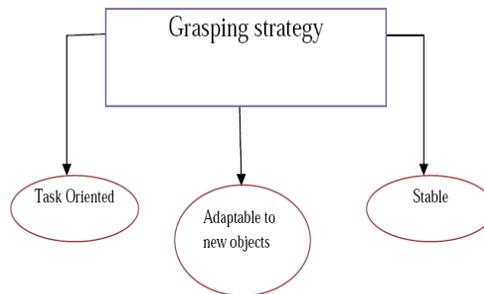
Where r_i denotes the position vector of the i th grasp point in the object coordinate frame which is at the centre of mass. If W is a $6 \times nm$ matrix called wrench matrix (for 3D objects) where its column vectors are the primitive contact wrenches. Where nm is the total number of primitive contact wrenches applied at the object by n fingers.

$$W = \begin{pmatrix} I_{11} \dots \dots \dots I_{16} \dots \dots \dots I_{nm} \\ r_1 \times I_{11} \dots \dots \dots r_1 \times I_{16} \dots \dots \dots r_n \times I_{nm} \end{pmatrix}$$

C. The Goal of a Grasping Strategy

We say that a grasp is stable if any disturbance on the object position or finger force generates a restoring wrench that tends to bring the system back to its original configuration. Always our first goal of grasping is the strategy to ensure stability. Nguyen introduces an algorithm for constructing stable grasps. Nguyen also proves that all 3D force closure grasps can be made stable. A grasp is force-closure when the fingers can apply appropriate forces on the object to produce wrenches in any direction to resist some external disturbing wrench. This condition may be confused with form-closure. The form closure induces complete kinematical restraint of the object and is obtained when there is no relative motion between the palm and the object which ensure the complete immobility of the object. Bicchi described in detail about these conditions. Hence, stability is a necessary but not a sufficient condition for a grasping strategy.

strategy to grasp Object



D. Force Closure / Form Closure Grasp

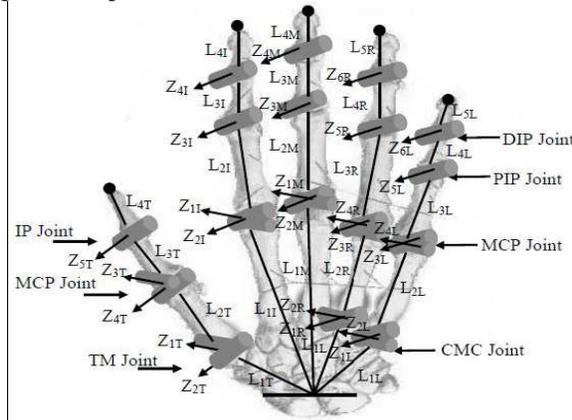
When the grasp is in any one of the condition: i.e., Form closure (or complete kinematical restraint) or Force closure i.e., the fingers ensures the object immobility then it can fulfil the condition of resisting any external disturbances or wrenches in any direction to compensate any external wrench applied on the object up to certain limit of magnitude.

If a grasp can resist any applied wrench, we say that such a grasp is force-closure. Precisely, we make the following definition that a grasp is a force-closure grasp if given any external wrench applied to the object, there exist contact forces such that the body is in equilibrium condition. One of the important features of a force-closure grasp is the existence of internal forces. An internal force is a set of contact forces which result in no net force on the object. It can be used to insure that contact forces satisfy friction cone constraints.

III. MODELLING OF THE ROBOTIC HAND

Since multi-fingered robot hands are designed to substitute the human hands, most anthropomorphic robot hands duplicate the shape and function of human hands. The size of the hand is a significant part in the research. The hand can be directly attached to the end of an industrial robot arm or play a role in the prosthetic applications. The structure of the fingers of human hands is almost the same and independent, as shown in Figure. The finger segments in human hand give us the inspiration to design an independently driven finger segment to construct a whole finger. The segmental lengths of the thumb and fingers are taken proportionately to hand length and hand breadth with a fixed wrist. Typically the hand mechanism is approximated to have 27 DoFs, which consists of 25 DoFs at different joints of the fingers and 02 DoFs at wrist. In the present study the wrist is considered as a fixed origin. Hence, only 25 DoFs are considered. The thumb is modeled with 5 DoFs. The index and middle fingers are modeled with 4 DoFs each. The ring and little fingers are modeled with 6 DoFs each considering two degrees of freedom each at CMC joint for palm arch. The Trapeziometacarpal (TM) joint, all five Mecapophalangeal (MCP) joints and two CMC joints are considered with two rotational axes each for both abduction-adduction and flexion-extension. The Distal-Interphalangeal (DIP) joints on the other four fingers possess 1 DoF each for the flexion-extension rotational axes. The thumb

and other fingers' parameters are tabulated. A simulation study of the kinematic model of the hand is carried out to test and validate the design and to consolidate the result considering the anatomy and anthropometric data of human hand. A kinematic model, characterized by ideal joints and simple segments, is developed to calculate the fingertip position as well as the work space. Given the joint angles, the fingertip position in the palm frame is calculated by the kinematic model. The Denavit-Hartenberg (DH) method is used to represent the relation between the coordinate systems and to determine the DH parameters for all the fingers. The global coordinate system for hand is located in the wrist assuring the transfer from a reference frame to the next one the general expression of the matrix. The transfer matrices are written for all fingers separately.



Kinematic model of human hand.

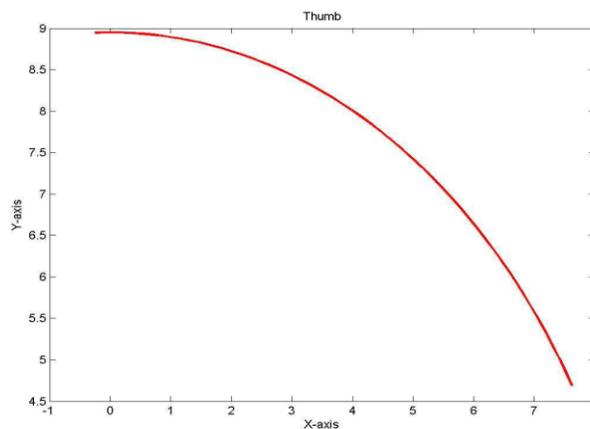
A. Thumb and Finger moment and the size of the object that can be grasped

It is of great importance to know which kind of object the hand can grasp. The type includes the size, weight etc. of the object. A program has been written to find the size of the object that can be grasped. The trajectory motion of the Thumb and Finger could also be known with the help of this program. The program is being written in MATLAB-7.1. On considering the following data the program has been written and the formulation part is done using Forward Kinematics. With the forward kinematics, given the hand posture, i.e. joint angles, we can know the fingertip position.

B. Forward kinematics

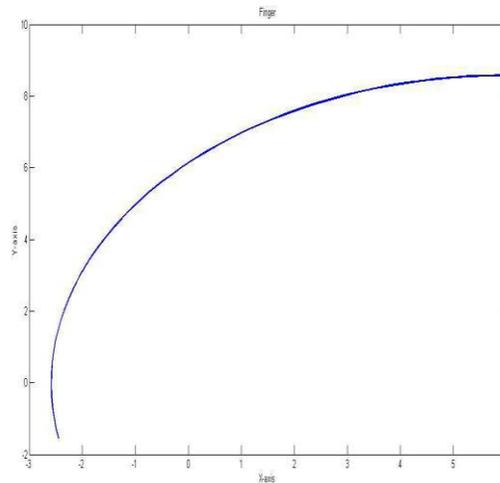
Kinematics is the study of motion. The forward kinematics is about finding an end effectors or tool piece pose given a set of joint variables. In our case we have considered the Thumb and finger as manipulator and have done the calculation. From basic trigonometry, the position and orientation of the end point of Thumb and Finger can be written in terms of the joint coordinates in the following way:

(a)For Thumb Figure: Trajectory motion of thumb



The above figure shows the moment of the thumb when the values of θ_1 are changed into fifty equal parts and the other values of θ_2 and θ_3 remains at maximum and minimum angle respectively. From above fig we can see when the x-coordinate is at 0 position the value of y-coordinate is maximum and slowly with the increase of x-coordinate in positive direction the value of y-coordinate goes down.

(b) For Finger Figure: Trajectory motion of Finger



The above figure shows the behaviour of the finger moment when the angle condition are kept same i.e., θ_1 are changed into fifty equal parts and the other values of θ_2 and θ_3 remains at maximum and minimum angle respectively. It shows the increase of the Y-coordinate with the x-coordinate moving in positive direction. This is because the reference point considered here is same for both. Hence the graph shows the reverse condition for the finger.

C. Computation of distance between Thumb and Finger

Distance Formula: Given the two points (x_1, y_1) and (x_2, y_2) , the distance between these points is given by the formula:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Using the above formula the distance “d” is calculated between the Thumb and the Finger.

The first two joints of the thumb and finger have been kept at maximum opening by keeping the θ_1 & θ_2 value maximum and the last joint has minimum opening by keeping the value of θ_3 minimum, so that the force applied by the tip of the thumb and finger should be maximum. The distance between the end points which decides about the size of the object was found to be 11.8468cm. So the object size of length 11.8468 cm. can be grasped by this hand.

D. Finger Configuration Condition

When some object is grasped by frictionless point contact there is provision that the contact force should always act in normal direction. Otherwise grasping is not possible. Hence this type of contact has got limited application like pushing. But generally there is always some friction between the grasped object and the hand. So it is very important to analyze about the effect of friction on the force. We have done coding in MATLAB-7.1 for seeing the effect of friction on the applied force. One more important thing that has to be considered is the angle at which the force is being applied. Because the maximum force that the finger can exert on the object is at normal direction. So for that also the coding is done in MATLAB-7.1 for analyzing the effect of applied force angle on the applied force.

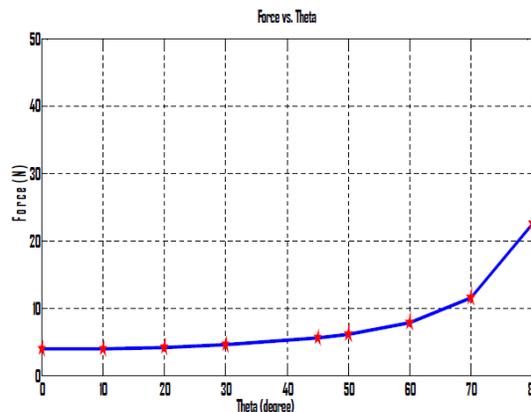


Figure: The effect of angle and coefficient of friction on the applied force by finger

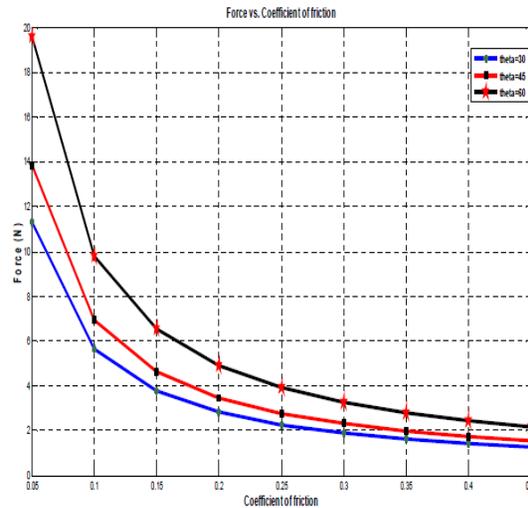


Figure: The effect of angle and coefficient of friction on the applied force by finger

The effect of incident angle on the contact force is shown in Fig.(a) while Fig.(b) shows the variation of the force value with different values of coefficient of friction taken from table. As the angle of force is increased the force required to grasp the object is increased. So, the best condition is that the force should be applied normally to the object so that the force required by the finger should be minimum. It can also be seen from the figure.6 that as the coefficient of friction is increased the force required by the finger is decreased. So we should choose the coefficient of friction (the finger-object interface) according to the necessity of them work.

E. Grasp Synthesis

We restrict our attention to systems of wrenches generated in the plane ($k = 3$) by hard fingers and assume Coulomb friction. While soft fingers can exert both pure forces and pure torques, a hard finger can only exert a pure force. The wrench associated with a hard finger located at a point x and exerting a force f is the zero-pitch wrench. Wrench is basically a single force applied along a line combined with torque. Any system of forces on rigid body can be described with wrench. Force and moment are encoded in wrench as:

$$w = \begin{pmatrix} F \\ F \times d \end{pmatrix}$$

The force equilibrium:

$$\sum_{i=1}^n F_i = \sum_{i=1}^n F_i \cos\theta_i + F_i \sin\theta_i = 0$$

: The magnitudes of the finger force

: The position vector of i th finger

The moment equilibrium:

= perpendicular distance of y component force

= perpendicular distance of x component force

IV. RESULTS

Firstly, by using Denavit-Hartenberg we have simulated the motion of finger and the spatial trajectories. The program was written in MATLAB-7.1 for obtaining the 3D model of workspace. Secondly, we have calculated the size of the object that can be grasped by applying forward kinematics. It was found to be 11.8468cm. The object of this length or breadth can be grasped by the hand. Lastly, the force applied by each finger and their point of application were calculated for five different objects so that the object should be in equilibrium, stable condition and Force closure condition. The table given below shows the Forces and the fingertip position.

Table1. Result for Rectangular object:

Finger	1	2	3	4	5	Finger	1	2	3	4	5
Force (N)	2.087	0.3922	0.5295	0.5687	0.5883	Force (N)	2.263	0.490	0.5687	0.4883	0.5883
Coordinate (m)	(0.0, 0.025)	(0.05, 0.046)	(0.05, 0.04)	(0.05, 0.032)	(0.05, 0.022)	Coordinate (m)	(0.0, 0.035)	(0.05, 0.051)	(0.05, 0.042)	(0.05, 0.032)	(0.05, 0.028)

Table 2. Result for Cylindrical object:

V. CONCLUSION AND FUTURE WORK

A. Conclusions

The present work aims at developing a kinematic model of a 5-fingered dexterous robotic hand with 25 degrees-of-freedom which may find its potential applications in industries. The calculation and simulation done in the present work is simple and the computational Complexity is also very low as compared to others. One of the aims of the present work is to contribute in the clarification of these methods, in order to help in wider utilization of these methods in the robotics grasping. Hence it can be conveniently used in real-time, multi-fingered grasp programming.

B. Future work

This work developed a novel method for grasping, but while we were finishing this development, new questions appeared that should be solved. For future work to continue this research, we propose that fingers were considered rigid bodies. The application of a soft finger and their analysis can add more realistic grasping.

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