Recognition of force closed point grasp for 2D object

AbhijitDas[1], Sankha Deb[2]

[1]CMERI, Durgapur (E-mail:abhijit.random739@gmail.com)

[2]Department of Mechanical Engineering, IITKharagpur (sankha.deb@mech.iitkgp.ernet.in)

Abstract

Robotic grasping of an object requires positioning the fingers of the robotic hand around the object in such a manner that the forces applied by the fingers on the object can create a force as well as moment equilibrium[1] and keep the object stable within the grasp. Research on robotic grasping is relevant too [2]. Recognizing a grasp of an object by a robotic gripper requires a definition of the grasp. In this paper we have compared different definitions of robotic grasp proposedby different researchers and we have proposed our definition of grasp and an algorithmic approach to execute the definition. The results obtained show the promising prospect of the approach.

Keywords:robot, grasping, equilibrium, stability, optimization, genetic algorithm.

Introduction and Background

There are many approaches which defines a force closed point grasp. All these approaches define some criteria based on which a force closed grasp is defined. Algorithms are generated thereafter to implement the grasps and computer programs are written to execute the grasps in the real world.

Primarily grasping an object depends on the following factors:

1. Object geometry. The planar/spatial orientation of the grasping surfaces and their frictional coefficient.
2. Number of contacts to grasp the object.
3. Value and planar/spatial orientation of the grasping forces.
4. Equilibrium of the grasping forces.
5. Stability of the object.

The differentapproaches to solve the problem of grasping have been the following:

1. Analytical,
2. Empirical,
3. Graphical, and
4. Evolutionary.

Among them, empirical and graphical approaches are explained using analytical proof. Evolutionary techniques are not always based on rigorous analytical proof.

Frictionless grasps on four edges

Weshall present below some approaches developed by researchers to define force closed grasp.

Firstly we will explain the approach by Nguyen for planar force closed grasp. The algorithm proposed by Nguyen [3] is graphically explained below:

A force closure grasp between four edges $e_1, \dots \dots \dots e_4$ can be constructed as follows:

1. Pair up two edges e_1, e_2 against e_3, e_4 such that the two sectors C_{12}, C_{34} are non null. By sector C_{12} we denote the smallest sector between the normals $-n_1, -n_2$. Similarly for sector C_{34}.
2. Check that the two sectors C_{12}, C_{34} counter-overlap, i.e $C_{12} \cap -C_{34} \neq \emptyset$.
3. Find the parallelogram Π_{12} by intersecting the two infinite bands perpendicular to and containing the edges $e_1$and e_2. Parallelogram Π_{12} is the locus of the point P_{12}, where the lines of forces w_1 and w_2 intersect. Similarly we find the parallelogram Π_{34} which represents the locus of point P_{34}, where lines of forces w_3 and w_4 intersect.
4. Pick two points P_{12}, P_{34} respectively from the parallelograms Π_{12}, Π_{34} ; such that the direction of the line joining P_{12} and P_{34} is in the counter overlapping sector

$$C = C_{12} \cap -C_{34}$$

DK Mandal and CS Syan (eds.), *CADCAM, Robotics and Factories of the Future*,
Lecture Notes in Mechanical Engg., pp. 357-365
DOI: 10.1007/978-81-322-2740-3_34

5. From point P_{12}, back-project along the normal n_1 (resp. n_2), to find the grasp point P_1, (resp. P_2), on edge e_1 (resp. e_2). Similarly we find the grasp points P_3 and P_4, by back-projecting P_{34} respectively along the normals n_3, n_4.
6. The four grasp points P_1, P_2, P_3, P_4 found as above form a force closure grasp G (P_1, P_2, P_3, P_4) between the four edges.

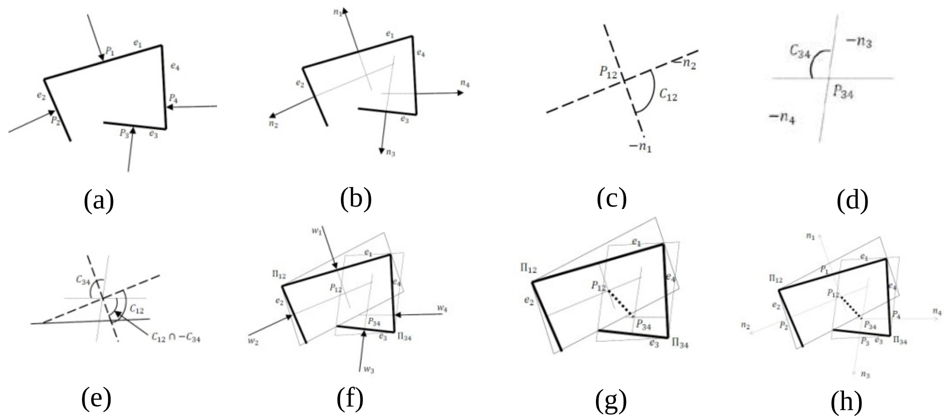


Figure 1: It shows a four finger grasp and its synthesis. (a) A four finger force closure grasp. (b) Side-normals of the object. (c) Construction of sector C_{12}. (d) Construction of sector C_{34}. (e) Over-lapping of the sectors. (f) Pick any two points P_{12} and P_{34}. (g) check the line $P_{12}P_{34}$ passes through C. (h) Back-project from points P_{12} and P_{34} along the side-normals to find the grasping points P_1, P_2, P_3 and P_4

Next we shall explain the approach by Mishra[4, 5]. His approach is rigorously mathematical, which can be graphically explained as below. Mishra's approach is explained for a three finger case.

For a three finger robot gripper [6] the relationship among the forces that can create an equilibrium grasp as well as counter the external disturbances can be obtained from the three contact forces F_1,F_2 and F_3 at points 1,2 and 3 (Figure 2) and their directions of application.

A system of three wrenches, w_i , i=1, 2, 3 corresponding to the set of three contact points is shown in Figure 2.

f_i= intensity of the wrench at point i.

u_{ix}= unit force direction vector along x direction.

u_{iy}=unit force direction vector along y direction.

u_{iz}=moment vector along z due to unit force vector u_i in the 'xy' plane.

$f_i w_i$is the 2 dimensional wrench of the force applied.

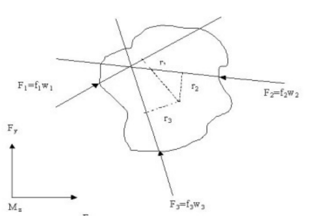


Figure 2: Planar forces acting on a 2D object of arbitrary shape

$$\begin{bmatrix} u_{1x} & u_{2x} & u_{3x} \\ u_{1y} & u_{2y} & u_{3y} \\ u_{1z} & u_{2z} & u_{3z} \end{bmatrix} \underset{AX}{\begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix}} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \ldots\ldots\ldots\ldots (1)$$

Figure 3: Force equilibrium acting on a 2D object of arbitrary shape

For an equilibrium grasp, the sum of all contacting forces and moments acting on the object must be equal to zero as shown in Figure 3.

The above equation in Figure 3 can have non-trivial solution if one of the following conditions hold good.

1. The rank of the matrix A, i.e. $r(A) = 2$. or in other words, w_3 is linearly dependent on w_1 and, w_2 or
2. The intersection of the convex hull of w_1, w_2 and the linear hull of w_3 is non-empty as shown in figure 3(a). i.e. $conv(w_1, w_2) \cap lin(w_3) \neq \emptyset$.
3. If we change the direction of F_3 then the origin of the force and moment space will lie in the interior of the convex hull of w_1, w_2 and w_3 as shown in figure 3(b). $origin \in intconv(w_1, w_2, w_3)$.

All the three conditions required for a non trivial solution of grasping problems point to the fact that F_3 has to be linearly dependent on F_1 and F_2. All the conditions satisfy equation 1 [5]. Graphically the conditions can be explained as in Figures 4(a) and 4(b).

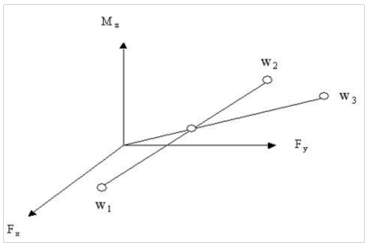


Figure 4(a): Non-empty intersection of the convex hull of w_1 and w_2 with the linear hull of w_3.

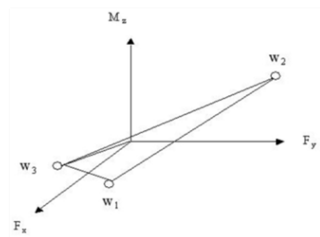


Figure 4(b): Location of origin in the interior of the convex hull of w_1, w_2 and w_3.

Empirical approaches were taken by Mirtich [7], Canny [7], Chinellato [8] and others [9, 10] to practically implement a stable grasp using three finger grippers without considering the analytical aspect of a stable grasp.Researchers have focused their attention more on finding out various empirical quality measures for implementing a stable grasp, namely shared features, grasp assessment features and configuration assessment features given below.

- Shared features:
  - Grasping margin:

Contact point farther from the threshold region (λ) extremes the feature implies stable grasp. Stability is defined as $\frac{\lambda}{d_i} - 1$, where d_i is the distance of the contact point from the both the extremes of the contact region.

$$Q_1 = \sum_i q_i \, ; \qquad where q_i = \begin{cases} 0 & where, d_i \geq \lambda \\ \dfrac{\lambda}{d_i} - 1 & where, d_i < \lambda \end{cases}$$

- Grasp Assessment features:
  - Force arrangement:

The forces should ideally be aligned at 120^0 to each other. This gives the most stable grasp. Force arrangement is defined in the following way where $\varphi_1, \varphi_2, \varphi_3$ are included angles among the force directions.

$$Q_2 = \frac{\frac{\pi}{27}}{(\pi - \varphi_1)(\pi - \varphi_2)(\pi - \varphi_3)} - 1$$

- Configuration assessment features:
  - Real focus deviation:

This feature measures the deviation of a grasp configuration from the ideal grasp. The measure is defined as follows: where, C_G is the focus of the ideal grasp,C_C is the focus of the real grasp, η is the maximum finger extension, $\mu$is the coefficient of friction.

$$Q_3 = \frac{\|C_G - C_C\|}{\eta\mu/2}$$

Proposed Methodology

The above approaches have derived complex parameters to define a force closed grasp. In our approach of defining a grasp,we have used an evolutionary soft computing based algorithm namely, genetic algorithm along with parameters which are very elementary in nature. Intuitively when we human beingsgrasp an object,

1. We do not apply force on the surface of an object so that the object slips out of our hand.
2. We try to envelop the object shape with as much surface area as possible for a good grasp and also try to put our fingers as midway as possible on the surface of the object.
3. At the first instance we try to hold the object in such a manner that the object becomes immobile within the grasp.

The conditions 1 and 3 may appear to be similar, but mathematically speaking they are different. Here we define them in the context of our requirement as follows.

1. Force arrangement:

The directions of forces acting on the surfaces of the object are within the friction angle between the finger material and object material. If any of the grasps is found to violate the definition of force arrangement, that particular grasp is penalized statically.

$$\begin{matrix} \tan\alpha \geq 0.3 \\ \tan\alpha < 0.3 \end{matrix} \begin{cases} unfit & \alpha = deviation\ of\ force\ dir.from\ surface\ normal \\ fit & 0.3 = friction\ coeff.between\ the\ finger\ and\ object \end{cases}$$

2. Grasping margin:

Ideal grasp points are assumed to be in the mid position of the sides assuming the object to be a 2D polygon. A grasp is dynamically penalized based on the extent of deviation of grasp point from the mid points of the sides.

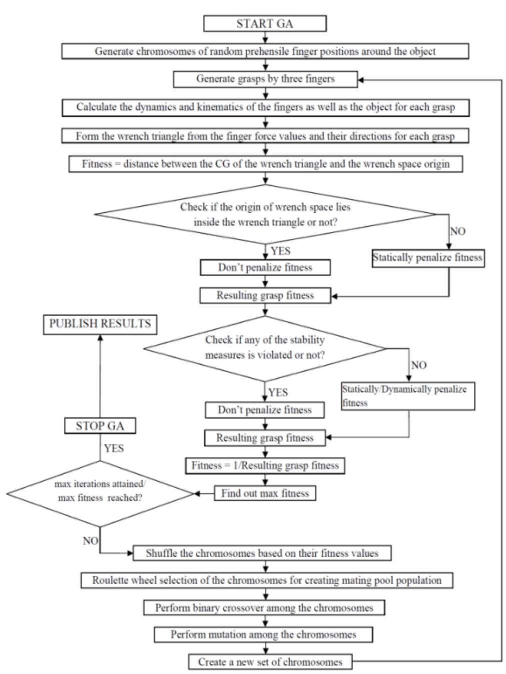
$$\frac{\Delta l}{\frac{l}{2}} \times unfit \qquad \begin{matrix} \Delta l = deviation\ of\ finger\ contact\ from\ mid\ point\ of\ side \\ l = length\ of\ the\ contacting\ side \end{matrix}$$

3. Real focus deviation:

The equilibrium grasp is ascertained by checking whether the origin of the wrench space is found inside the wrench triangle or outside. Each grasp is either penalized or not penalized based on this information.

$$\begin{matrix} origin \in int\ conv\ (w_1, w_2, w_3) & fit \\ otherwise & unfit \end{matrix}$$

The quantities fit and $unfit$ have been assigned numerical values in the algorithm.



Population size: 40,
Maximum iteration: 100,
Crossover probability: 0.98
Mutation probability: 0.02

Figure 5: Flow chart of the developed algorithm and parameters

These conditions henceforth will be called stability measures because these conditions will be responsible for guiding a random process of grasping to the understanding of the process and finding out a feasible grasp. These conditions will also provide a stable grasp. The corresponding follow chart of the proposed algorithm is shown in Figure 5.

Results and Discussions

The goal of this algorithm is to check if the CG of the objectafter grasping coincides with the CG of the object before grasping or not. The closer the two points are located to each other, the better the grasp is supposed to be. We have experimented with different shapes,with different parameters of the genetic algorithm, obtained through experimentation. The results are given in Figure 6.

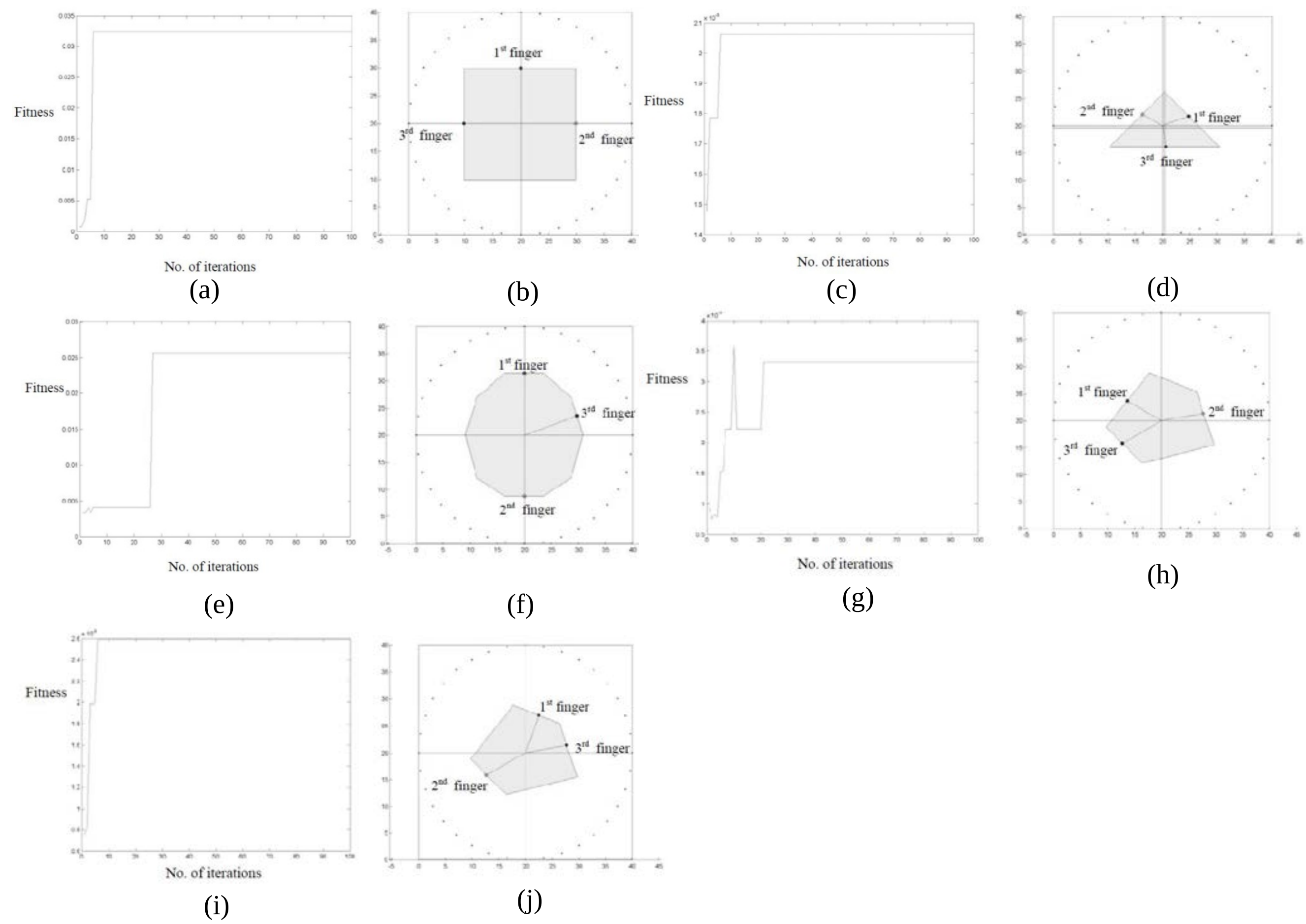


Figure 6: Figures (a), (c), (e), (g), (i) show the convergence of the genetic algorithm for 100 generations. Figures (b), (d), (f), (h), (j) show the optimal grasping points on the boundary of the 2D objects after 100 generations.

In all the given instances, the algorithm has been found to give satisfactory results. Through evolution of the solutions by the genetic algorithm, it refines the gripping positions to ultimately come out with the optimum result. In all the cases,the same assumptions and genetic algorithm parameters have been used to arrive at the optimum result. Analysis of the genetic algorithm outputs shows that in all the cases it converges very quickly, but the algorithm was run for 100 generations to see if there is any further improvement. It was seen that the computing time increases with the number of sides. One more reason of larger computing time was that the whole program runs on MATLAB platform in WINDOWS XP operating system. The computing time can be brought down if the whole code is translated in C language.

Conclusions

The problem of recognizing a grasp of an object by a robotic gripper requires a definition of the grasp. Most of the above previous approaches found in the literature review had derived complex parameters to define a force closed grasp. In this paper, we have compared different definitions of robotic grasp proposed by different researchers and we have proposed our definition of grasp, and to execute the definition we have used an algorithmic approach based on application of an evolutionary soft computing based algorithm GA along with parameters which are very elementary in nature. The algorithm is found to be a very robust one and can perform satisfactorily for many different types of 2D object shapes. But as most of the 2D shapes encountered in reality are rectangular, triangular or circular, so in that respect its performance is very much acceptable. The main drawback of this algorithm is that the shape vertices are to be input manually to the computer program. In future, it is proposed that an algorithm will be developed that will approximate the shape of an object from its 2D image with minimum number of straight lines, and the shape vertices will be automatically generated from the approximated image. As the main aim of this work is to find out the prehensile positions of the fingers to grip the object, so the shape approximation will not degenerate the solution accuracy.

References

1. Realeaux F.,1876, Kinematics of Machinery,*Macmillan and Company, London*,
2. Tovar N. A. and Suarez. R., 2014, Searching force-closure optimal grasps of articulated 2D objects with n links, *19th IFAC World Congress, Cape Town, South Africa. August 24-29, 2014,* page 9334-9340.
3. Nguyen Van-Duc,1986, The Synthesis of Stable Force-Closure Grasp, *Technical Report 905, MIT Artificial Intelligence Laboratory, Massachusetts Institute of Technology.*
4. Mishra B., Schwartz J.T. and Sharir M., 1987, On the Existence and Synthesis of Multifinger Positive Grips,*Algorithmica, Springer-VerlagNewYork Inc.*, page 542-558.
5. Mishra B. and Silver, N., 1989, Some Discussion of Static Gripping and Its Stability, *IEEE Transactions on Systems. Man. And Cybernetics*, 19 (4).
6. Deb S.R. and Deb S., 2010, Robotics Technology and Flexible Automation, Tata McGraw Hill Education Private Limited, 2nd Edition.
7. Mirtich B. and Canny J., 1994, Easily Computable Optimum Grasp in 2D and 3D, *Procd. of the 1994 IEEE International Conference on Robotics and Automation, San Diego, CA, May,* page 739-747.
8. Chinellato E.et. al., 2003, Ranking Planar Grasp Configurations for a Three Finger Hand, *IEEE Intl. Conf. on Robotics and Automation, Taipei, Taiwan,* page 1133–1138.
9. Baker B.S., Fortune S. and Grosse E., 1985, Stable Prehension with Three fingers, *Procd. of the 17th Annual Symposium on Theory of Computing, Providence, RI,* , page 114-120.
10. Ponce J.and Faverjon B., 1995, On computing three finger force closure grasps of polygonal objects, *IEEE Transactions on Robotics and Automation, Vol. 11, No. 6,* page 868-881.