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A New Grasp Quality Measure Considering Physical Limits of Robot Hands

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Abstract

In this paper, we introduce the extended grasp wrench space (GWS) to identify the applied location and the magnitude of the critical external wrench, in conjunction with the task wrench space (TWS) that is made up of all the possible external wrenches produced from the unit normal force to the surface points of the grasped object (that is, object wrench space(OWS)) In the extended GWS, the torque bound of each joint of the robot hand is considered in determining the grasp capability. Through the convexity analysis and linear programming technique, we propose a new way to obtaining an enhanced grasp measure which shows the clear physical meaning. We verify the proposed grasp analysis and quality measure using visual grasp simulator and various shaped polygonal objects.

1 Introduction

Despite the long history of research, the grasp planning methods for multi-fingered hands are not so efficient until now. This may be due to the fact that the grasp planning task requires a complicated and time-consuming mathematical computation associated with the convexity theory to confirm that the finite number of friction cones at the fingers' contacts positively spans any external wrench.

Liu et al. [1] introduced the force-closure grasp using ray-shooting technique, and grasp planning using force-closure grasp condition. Recently, Goldfeder et al. [2] presented a grasp planning method by simplifying object shapes using decomposition. Kirkpatrick[3] suggested the largest inscribed sphere that just fits within the convex hull of Grasp Wrench Space (GWS) as a task independent grasp quality measure. Li and Sastry [4] proposed to use the volume of ellipsoid generated by the grasp matrix as a measure of grasp quality. They also suggested Task Wrench Space (TWS). Pollard [5] introduced the Object Wrench Space (OWS) which is generated by object's geometry. Borst et al. [6] proposed a method to define the grasp quality measure using GWS, TWS, and OWS, where, in order to find grasp quality measure, they constructed TWS using OWS and Mass Wrench Space(MWS) and computed the circumscribe ellipsoid to the TWS and calculated the minimum distance from the ellipsoid to the convex hull of GWS.

In this paper, we propose a new grasp qualification measure which can confirm the capability of resiting under the disturbance forces. This measure basically seeks a weakest object position under the external force. The measure is on the basis of the minimal scale value between TWS and GWS, which was originally proposed by Borst et al. [6]. However, instead of using the circumscribed ellipsoid of TWS, we use the exact information of wrenches in TWS in order to obtain the minimal distance to extended GWS. We also apply this method to handle the case where the gravitational force acting on the object is the major source of external force.

The rest of the paper is organized as follows. In section 2, we present the details of our new grasp method, and we verify the theoretical result through the simulation study in section 3. Finally, section 4 addresses the conclusion and future works.

2 Grasp Quality Measure

2.1 Extended grasp wrench space

As shown in Fig.1, the force at the tip of a robot hand has a relation with the joint torque. Using this relation, we generate GWS which contains the information of joint torque range. Since the joints of the robot hand have torque limits, we can calculate the maximum end effector(contact point) force which is generated by the robot hand through the linear programming. We know that force and torque of each

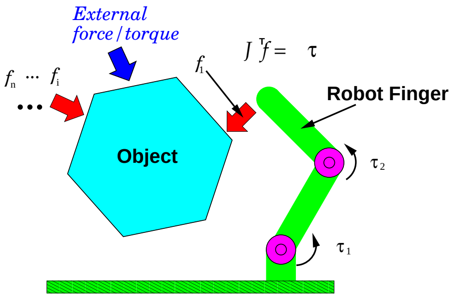


Figure 1: Force-torque relation in a real hand.

finger are related such as

$$\tau_{robot_i} = J_i{}^T f_{end,i}, \tag{1}$$

where $J_i \in \Re^{m\times n}$ is the Jacobian matrix of finger i. If we take the pseudo inverse of J_i to (1), we obtain

$$(J_i J_i{}^T)^{-1} J_i \tau_i = f_{end,i}. \tag{2}$$

Since the finger tip force $f_{end,i}$ indicates a different direction from the normal direction in the object surface, the pure component of $f_{end,i}$ toward the normal is obtained by

$$f_{c_i} = n_{c_i} \cdot f_{end,i}, \tag{3}$$

where n_{c_i} is the normal vector at contact i. Because we know the bound of each finger joint torque, the maximum of f_{c_i} is easily achievable by the linear programming such that:

$$\begin{aligned} \text{Objective function :} \quad & f_{c_{i_{max.}}} = n_{c_i} \cdot (J_i J_i{}^T)^{-1} J_i \tau_i \\ \text{subject to :} \quad & \tau_{min.} \le \tau_i \le \tau_{max.}, \end{aligned} \tag{4}$$

where $f_{c_{i_{max}}}$ is the contact force on the object surface and $f_{e_{max}}$ is the maximum finger tip force. Now we can make the grasp wrench space using these $f_{c_{i_{max}}}$ with the assumption of the friction contacts. While the conventional wrench space does not consider the actual scale of force at the contact point, the current grasp wrench space, i.e., the extended wrench space, takes into consideration the physical ranges of feasible contact forces from the fingers.

2.2 Suggested grasp quality measure

In order to implement our suggested grasp quality measure, we assume that object models are discretized into a sufficient number of facets(polygons) at the surfaces. We suppose that each facet of the object model is possibly subject to a unit external force acting into the normal surface. Thus, we can construct TWS by combining all these unit external forces. Due to the nature of TWS, it has a large number of directional vectors which point from the origin to the wrenches of TWS. The minimal scale value between the convex hull of TWS and that of the extended GWS will be the grasp quality measure we suggest; furthermore, the corresponding location where the minimum of scale is found is the fatal spot. The following is the procedures of finding the minimum distance between TWS and the extended GWS.

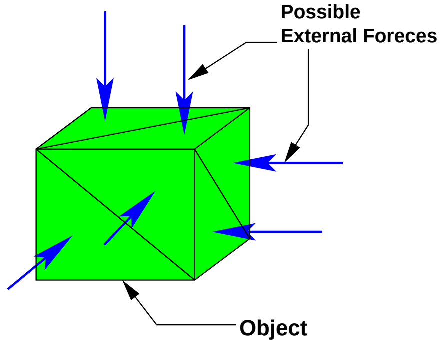


Figure 2: Possible external forces on an object that make OWS.

1. Make a discrete object model and create the corresponding OWS(which becomes the TWS).
2. Calculate convex hull of TWS.
3. Find the wrench vectors in TWS which makes the boundary of the convex hull of TWS.
4. Calculate the distance between convex hull of TWS and convex hull of extended GWS using the ray-shooting method.

The ray-shooting method is implemented as follows: First, define that the *i-th* wrench directional vector of convex hull of TWS is $T_{v_i} \in R^6$ and the *j-th* wrench vector of convex hull of extended GWS is $G_{v_j} \in R^6$. Then, find the hyper-plane equation of the convex hull (extended GWS) intersected to extended line from T_{v_i} by using the linear programming which maximizes the object function z such that

$$\begin{aligned} \text{Objective function :} \quad & z = T_{v_i}^T x \\ \text{subject to :} \quad & G_{v_j}^T x \le 1 \quad j = 1, 2, \ldots, N \end{aligned} \tag{5}$$

Finally, find the minimum scale between T_{v_i} and the intersection point in the boundary of the convex hull of extended GWS for all i. This minimum scale value

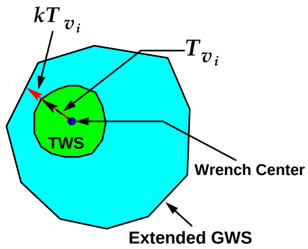


Figure 3: Schematic of the grasp measure.

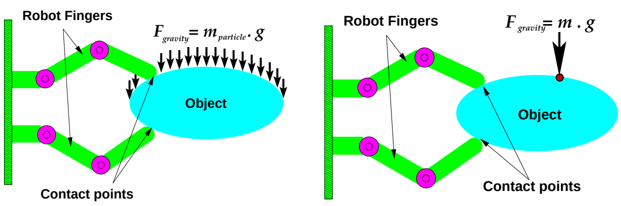
is the grasp measure, which is mathematically written as

$$Q_g = \{k \in \Re |\, \min(k), \text{for } \forall T_{v_i} \& \; kT_{v_i} \in \partial(\text{EGWS})\}$$

where k is a scalar constant and ∂(EGWS) denotes the surface of the extended GWS. (Please see Fig.3 for the schematic of the grasp measure.) Thus, it is clear that our measure value directly implies the magnitude of the maximum external force applied normal to a particular facet of the polygonal object without causing unstable grasp. Since we are able to compute that a particular T_{v_i} yields the minimum scale value, the corresponding facet of the object surface where the T_{v_i} is created from the external is the weakest spot.

2.3 Application: Under gravity load

We may apply the proposed grasp measure to verify the grasp stability to the case where the only external force is from the gravity. Since the gravity is acting on each particle of the rigid object as shown in Fig.4(a), it is tricky to handle the distributed load in practice. So an easy way is to use the equivalent single force at a particular point as shown in Fig.4(b). If this equivalent force does not exceed the allowable load at the location, then we can say that the grasp under the gravity load is stable.



(a) Distributed gravity load (b) Equivalent gravity load

Figure 4: Gravity load.

Table 1: Results of the simulation with different objects.

Object model	Box	Cylinder	Cup	Arbitraty
Grasp type	Pinch	Spherical	Spherical	Spherical
Grasp measure (Q_g)	1.782	1.598	0.745	0.167
Meshes (units)	1200	1044	1740	306
Calculation time (sec.)	0.198	2.122	42.692	1.818
X	0.999	0.000	0.000	0.961
Y	0.000	0.000	0.000	0.260
Z	0.000	0.999	0.998	0.075
Rx	0.000	-0.033	0.053	0.011
Ry	0.0367	0.016	0.011	-0.043
Rz	-0.018	0.000	0.000	-0.002

Table 2: Results of simulation with different grasp types and contact configurations.

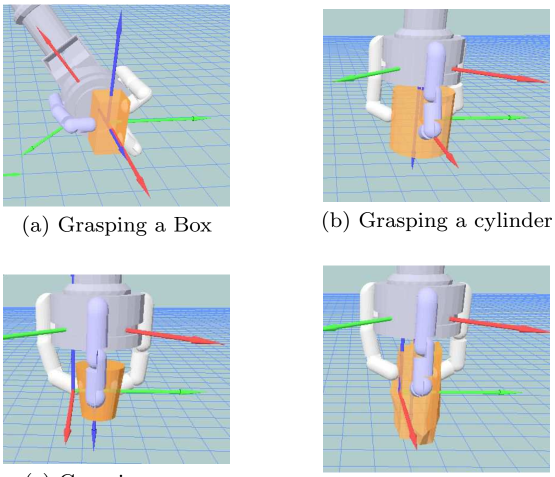
Object model	Box	Box	Box
Grasp type	Spherical	Pinch	Pinch
Grasp measure (Q_g)	2.181745	1.821307	0.001641
Meshes (units)	1200	1200	1200
Calculation time (sec.)	0.204855	0.215650	0.225968
X	-0.999179	0.999158	0.999158
Y	0.000000	0.000000	0.000000
Z	0.000000	0.000000	0.000000
Rx	0.000000	0.000000	0.000000
Ry	0.036717	0.036716	0.036716
Rz	-0.017109	-0.018295	-0.018295

3 Simulation

In the simulation, the considered robot hand is assumed to be of the Barret hand type, having three fingers, each being 3-DOFs. So, the total DOFs of the hand are nine. In the simulator, we use taxonomy based preformed grasp for grasping the object and use sampling method to find contact points, which was addressed in [7]. In this simulation, we assume the torque min-max limits of the joints fingers are $\pm$ 1.

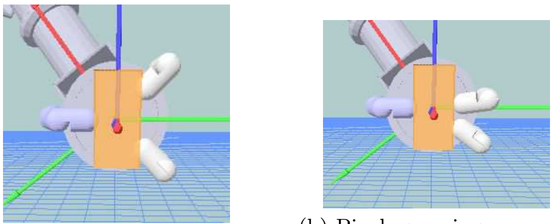
We use the objects including box, cylinder, cup type and arbitrary shaped object. These 3-D object models which are used in our simulation have hundreds or thousand polygons. In our test, we apply the pinch grasp and spherical grasp for grasping a box object, spherical grasp for grasping a cylinder, a cup and an arbitrary shaped object.

Firstly, we compare the grasp measures for different objects. Fig. 5 shows the screen shots of grasping the target objects, and Table 1 shows the corresponding results such as grasp types, measure values, calculation time and weakest directions. From the figure, we can confirm the validity of the computed weakest position of the object. Secondly, we compared the grasp qualities between grasp configurations. In this test, we test two different sets of contact points, where one is the marginal force-closure and the other one is strict force-closure as illustrated in Fig. 6. The summary of the result is given in Table 2.



(a) Grasping a Box (b) Grasping a cylinder (c) Grasping a cup (d) Grasping a arbitrary shape

Figure 5: Screen shots of various grasps.



(a) Pinch grasping a cup on the stable contact points (b) Pinch grasping a cup on the marginal contact points

Figure 6: Screen shots of grasps for the different finger configuration and contact position.

4 Conclusion and Future Works

We have proposed the extended grasp wrench space using the robot hand's physical torque limits. Using the extended GWS, a new grasp quality measure has been suggested, along with the procedures of computing the measure. Through the proposed measure, we could find the weakest spot of the object surface under the external force for each finger configuration. We have demonstrated our algorithm for examples of various object grasps. For each example, the grasp quality measure has been computed together with the weakest spot. In the future, a more efficient way to reduce the computation time will be studied on the basis of the proposed framework. Also, we think of extending the algorithm to cope with the gravitational force field as the external force on the object surface.

Acknowledgements

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