Reactive Algorithms for 2 and 3 Finger Grasping

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Abstract

We study the problem of grasping an unknown 2-$\frac{1}{2}$D object with constant horizontal cross section using three types of robot hands. We consider a three fingered hand, a two fingered hand and a standard parallel jaw gripper and equip these with distance and angle sensors that are located at the fingers or jaws. The sensors used are simple, provide only limited information, but allow us to reactively find a good grasp on an unknown convex object. When grasped the forces applied will be normal to the object boundary. Furthermore the object is not disturbed as the grasping points are being sought.

1 Introduction

In the past, the usual approach to grasping has been to assume an accurate model of the object to be grasped and from such a model, an off-line geometric algorithm determines a set of grip points, where the fingers are then placed. (See Mishra et. al. [MSS87] and Mishra and Teichmann [MT92]). Once the grip points have been determined, the geometry of the object is deemed irrelevant. Here we use the local geometry of the object to find a set of grip points and we also solve the local motion planning problem of getting the fingers to their grasping positions. Furthermore, our algorithm is non-disturbing in the sense that it does not cause any movement of the objects except for the movements desired.

A different approach has been taken by Goldberg in [G91, GF93], where a gripper is designed that requires no sensory information but rotates the object as it's being grasped.

1.1 What is a Reactive Algorithm?

Our "algorithm" is rather different from what is usually understood by algorithms: the robots (i.e., actuators and sensors) themselves are active components of the algorithm, performing "computations" much like an analog computer in conjuncts with a digital computer. For this reason, the "algorithm design" also implies a careful choice of the participating actuators and sensors and their placement. Thus, the algorithm does not separate in any meaningful way phases of "digital planning" interrupted by "analog actuation and sensing". As a result, our reactive algorithm is much smoother in operation.

By a reactive algorithm, we mean a simple algorithmic scheme where a robot's sensors determine immediately the actions of the actuators. However, note that the actuators themselves may interact with the sensors (e.g., by moving them or occluding them, etc.) to close a feedback loop and thus causing further goal-driven as well as corrective actions.

In the same spirit, we have developed earlier a reactive algorithm for a modified parallel jaw gripper, where the jaws are wider than the object and are equipped with light beam sensors, see [TM93].

Here however we consider three fingered grasping, two fingered grasping and a parallel jaw gripper with jaws that are are narrow compared to the object. We search for the gripping points by following the object boundary in a way that is dictated by the boundary until some geometric conditions are satisfied, which will then guarantee a grasp. The object is not known in advance, we only know that it is convex and and has fixed horizontal cross-section. We also assume initially that its boundary is smooth, but this restriction will be removed later.

First consider a gripper that consists of 3 fingers whose endpoints move in a plane. The fingers can move to arbitrary positions within certain bounds, but their order around the triangle they are forming must remain the same.

Each finger is equipped with simple sensors, as described in the next section, which allow the fingers to follow the contour of the object to be grasped, and locally determine the angle of the object boundary it is close to.

1.2 Sensors

Each finger is equipped with the following sensors:

1. An omni-directional distance sensor, which returns the distance of an object in any (planar) direction. Its range can be very small, only what is required for tracking the boundary of an object that lies within close proximity to the finger.

2. An angle sensor. If the finger is close to an object as defined by the previous sensor, we require the sensor to return the angle of the object

boundary at the closest point.

These sensors can be implemented by using for example an array of distance sensors similar to the optical Okada sensor [O82] or rotating the fingers such that some sensor remains normal to the object. We are in the process of designing such sensors, so that they are as small and as robust as possible.

1.3 Primitives

In order to describe our algorithm at a high level we assume that the following primitive can be called upon. The main basic operation our algorithm will need is the following of the object boundary by a finger. This has already been implemented on various robotic platforms, see for example [J92].

2 Three Finger Reactive Algorithm

Our algorithm for finding a three fingered grasp is based on the paradigm of finding a locally minimal area triangle that encloses the object. A geometric algorithm for convex polygons can be found in [OAMB86].

> **Theorem 1** [K86]: *If T is a local minimum among triangles containing a convex body B, then the midpoint of each side of T touches B.*

It can also be shown that if the midpoint of an edge e of a triangle does not touch the object, then e can be perturbed such that its midpoint after the perturbation lies inside the original triangle. This is precisely how the algorithm operates. In essence we minimize a potential function defined by the triangle area, whereas in [TM93], we minimize the distance between the two jaws of the parallel jaw gripper.

Given such a triangle, we note that the lines through its edge midpoints and perpendicular to their corresponding edges are concurrent at the point which is the center of the circle circumscribing the triangle. See figure 1. If we place the three fingers at the edge midpoints, we get a planar force closure grasp that does not rely on friction. The finger forces will be chosen such that they sum to 0. Planar torque closure is obtained, if we allow for sufficient friction.

We now describe the algorithm. Let B be the object to be grasped. For simplicity of exposition, when we say a finger is at point p of the boundary,

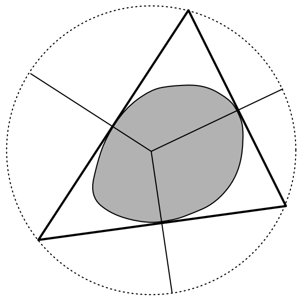

Figure 1: Forces applied at edge midpoints meet.

it is in fact in close proximity of the object, and does not touch it. (It is on the boundary of a sligthly enlarged object. The point p will be the closest point to the finger on the boundary of the original object.) The tangent to the object at that point is still well defined, by convexity. Note that given three such finger positions, the sensors at the fingers indicate the object tangents, so we know the triangle they form.

Phase 1

In the first phase we find some triangle that contains the object. We assume the object lies somewhere "between" the fingers, such that when we close the fingers, say along three concurrent lines at angles of 120 degrees with each other, each finger comes in proximity with the object.

Let p_0, p_1, p_2 be the corresponding points that lie on the boundary of B. Let t_0, t_1 and t_2 be the object tangents at those points. If the tangents form a triangle the first phase is done. Otherwise we pick an unbounded edge and "rotate" it by movings its finger along B in the unbounded direction. This procedure must lead to a finite triangle. It is also possible to arrive at a triangle with all but one edge midpoints touching, by keeping the distance of say p_1 and p_2 to t_0 the same. This is described in the full version of the paper.

Phase 2

In the second phase we find a locally minimal area triangle enclosing B. The procedure is simple: since we are looking only for a local minimum in the area, we can use local methods. Each finger divides its triangle edge into two segments. Consider the ratios of the largest segment to the total edge

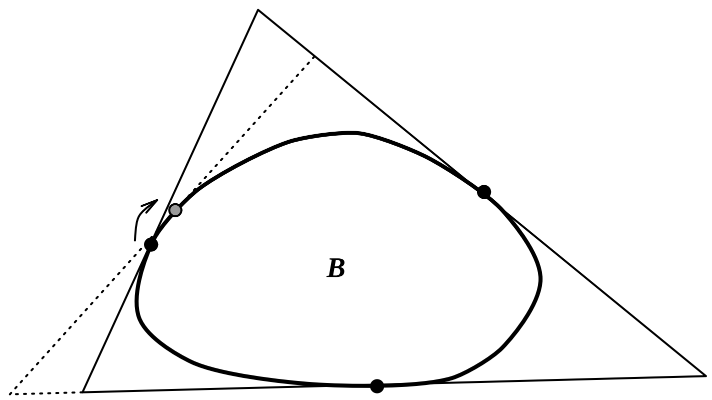

Figure 2: Steps of the algorithm.

length. This number is between 0 and 1, and is 1/2 if the finger is at the edge midpoint. Pick the edge whose finger is proportionally the furthest from the midpoint, i.e. whose ratio is largest. Then move the corresponding finger along the object boundary, in the direction of the largest segment. This will reduce the ratio and it also reduces the area of the triangle since the new midpoint moves inside the old triangle. See figure 2.

We iterate this step until all fingers are at their edge midpoints. At this point the normal lines at the finger points are concurrent and we found a grasp. Convergence is guaranteed by the fact that the area of the triangle decreases during every move.

Dealing With Uncertainty

After some point the algorithm will reach the limit of the sensor resolution and will oscillate between various nearby positions close to the local minimum. This can be solved by accepting a small error in the finger positions so that they are close to the edge midpoints. The cases where the algorithm will be the most sensitive to errors will be when the triangle is very skinny. Then a small motion of a finger will have larger consequences on the edge length and its relative position. However, since we assume some degree of friction, we simply assume that the friction is sufficient to allow for the forces to be concurrent, irrespective of sensor angular error.

This algorithm does not work for nonconvex objects since for such objects the midpoint of an edge of a locally minimum area triangle does not necessarily lie on the object boundary. It might still be possible to use it locally,

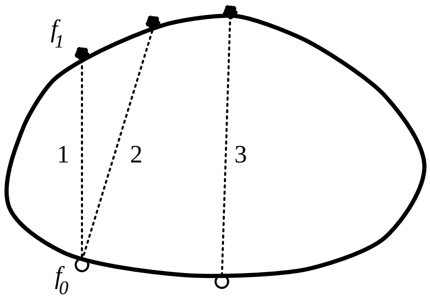

Figure 3: A few steps of the two finger algorithm.

and we are investigating this. If we allow the fingers to grasp at object vertices, and if we consider that at a vertex all the possible normals between the normals of the adjacent edges are present, then this algorithm can be used on polygonal objects.

3 Two Finger Algorithm

This section describes a simple reactive algorithm for finding a two finger grasp. The hand model is as follows. The two fingers slide on an axis that is parallel to the grasping plane, and let the midpoint of the two fingers be the center of the gripper. Call the *finger normal* the direction from the finger to the midpoint. Here we assume similar sensors as previously but we do not require angle measurement, only the information on whether the angle formed by the inward pointing normal to the object at the finger position and the finger normal is 0, positive or negative. Again, we assume that the object has a smooth boundary and is convex.

There must exist a pair of points on the boundary of the object such that the normal lines at both points are in fact the same line. This can be seen by considering the pair of supporting lines, one on each side of the object, and rotating this pair until it reaches a local minimum. Then the contact points satisfy the above requirement.

We find such a pair of points as follows (refer to figure 3.)

We assume that initially the object is somewhere between the two fingers. The fingers close until one of the sensors indicate proximity. Call this finger f_0, the other f_1. Then the gripper is rotated until the finger normal of f_0 is normal to the object. Such a rotation will in absolute value be by less than $\pi/2$. If during this rotation f_1 becomes close to B, then it starts to track the boundary of B in the direction away from f_0. Otherwise, close the fingers along their axis (translating the center if necessary) until f_1 becomes close to B as indicated by its sensor.

Now to find the grasping points as described above, we "rotate" the gripper by following B's boundary using f_0, keeping its axis normal to B, and f_1 also following B. Then the grasp is found when f_1's normal is also normal to B. This must happen by a comment above. Note that we don't need to rotate by more than 2π.

Again, under the same conditions as for the three finger case, we can use this algorithm for the polygonal case.

4 Parallel Jaw Gripper

The algorithm in the previous section can be extendend to apply to a parallel jaw gripper with narrow jaws, as many grippers currently have. Each jaw is equipped with a row of distance sensors, the number depends on the expected object curvature and jaw size. Each such sensor points towards the other jaw Furthermore, omnidirectional sensors should be attached at each jaw endpoint. This allows the algorithm to operate on the same type of objects as the previous algorithm.

More specifically, boundary following is achieved by keeping the distance detected by the closest sensor small, and the additional requirement of axis normality is satistfied by keeping equal the distance indicated by the two sensors placed at the jaws ends.

5 Concluding Remarks

It remains to be seen how these algorithms perform in practice. We are currently developping a reactive gripper, that will accomodate the implementation of several of these algorithms.

Also many variations are possible. For example, we can replace the proximity and angle sensors by force sensors, but we lose the nondisturbing quality.

It would be interesting to find algorithms that require less sensory information, for example require only the sign of the angles at the fingers instead of the exact angle for the three finger case. This would make the algorithm more robust and simplify the sensors. Generalization of these algorithms to non convex objects would be desirable.

Finally, these techniques can be extended to three dimensional objects and four fingers, and this will be discussed in a future paper.

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