Stable Grasps by Path Planning using Artificial Fields*

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Abstract

This paper proposes a new method for grasping an object positioned in a cluttered workspace. The grasping of an object usually relies on the analysis of its contour in order to determine the contact points for the fingers of the gripper. The planning of the positioning of the real gripper in the workspace at the chosen points is often considered as a separate problem. The method proposed in this paper plans the placing of the gripper onto the contour of the objects thereby considering the size and shape of the fingers. A collision-free grasp for a gripper is found by simulating an attractive motion of the gripper towards the object until a configuration is found that satisfies the stability requirement. The technique relies on artificial fields defined over the workspace which are used to guide the motion of the gripper and to evaluate grasp configurations. Appropriate strategies are used to overcome local minima during the search.

1 Introduction

Most traditional grasp planners rely on the supposition of complete information about the geometry of the objects and assume that all their parts can be reached by the grasping

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device. This subsumption means that the object is removed from the real workspace and that it is placed in a virtual free space where problems of contacts and collisions are ignored. The goal of the system is to search for a stable grasp and, assuming in the same case friction, it usually models grasping fingers as points, without considering their shape and size. In this situation the supposition of point contacts between the fingers and the object is only valid when the finger width is small with respect to the object. If the finger width and geometry cannot be ignored, the problem of grasping becomes more complicated because the fingers must be placed more carefully [Hol90]. The problem of positioning fingers around the object is then solved by searching for a set of points that guarantee a good balance between forces and torque [LP76] [LP81], somethimes considering the behaviour of the grasp according to little perturbations of the global system. Good solutions to this problem are found considering a spring-like model of the finger and using a potential function to evaluate the grasping set of points [HA82][Cut85][Ngu89]. In general more than one set of satisfying contact points can be found and a choice has to be made. The problem to check whether a grasping configuration is reachable for a real gripper, means with certain shape and size, in a real workspace, means with contacts and collisions, is always left to the next phase of the grasping procedure or sometimes skipped. A first step in this phase is to search for a collision-free configuration for the gripper according to the chosen contact points. Next a collision-free path must be planned from an initial gripper configuration to this one. It is clear that in a cluttered workspace a lot of preselected points can not be reached, and, in practice, this phase require more extensive computation and is not always guaranteed to find a solution. Therefore it is often necessary to repeat the process for another set of contact points. Detailed descriptions of other systems using these methods can e.g. be found in [INH$^+$86][MP89].

Our method does not start from the exhaustive analysis of the geometry of the object but consider, first of all the problem of planning the collision-free motion of the gripper towards the contour of the object hereby generating a grasp. The gripper and the objects are considered in the real workspace and represented with their shape and size. In the system the object to be grasped "generates" an artificial potential field that attracts the graping device. In order to generate this field it considers two points. First, to garantee a grasp, the gripper must be attract from the borders of the object. Second, to cover aspects of grasping that the system does not explicity handles, like stability at perturbations or objects weight, the gripper must grasp the object as near as possible to the center of mass or to some other points (called focus points) chosen by the user. The artificial field is then a combination of a field that attracts the gripper near to the border and a field that attracts the gripper near to a focus point of the object. This field is used to drive the motion of the gripper until a grasp configuration is found. After this a stability test is activated and if stability is not achieved we apply local retraction strategies and restart the motion planning again until we find a stable grasp configuration. When a stable grasp is found the system is able to use certain heuristics in order to obtain new stable positions that, for example, are closer to the focus point.

Our system can be applied in situations where complete geometrical knowledge of the object is present, but it is also possible, to search for a grasp, using the knowledge about the object silhouette or, for planar objects about their bitmap representation. In order to show the functionality of the method we have experimented with a simulation of a two-fingered parallel gripper using camera images of planar objects in a workspace mapped to a grid. These "analogical simulations" in discrete grids are known to be a valuable tool for testing planning techniques for assembly tasks because it facilitates collision detection and contact analysis [Gam91]. In this paper we do not deal with the vision techniques that are needed to obtain the images.

The next section of this paper gives an overview of path planning using articial force fields. The third section then explains the artificial grid fields that are used to guide the grasping. A following section explains the idea of a stable grasp for a parallel gripper considering the size and shape of the fingers. In section 5 and 6 we describe the procedure for simulating the motion of the gripper in the fields and explain the search heuristics in order to obtain a satisfying grasp. We end by showing some examples of grasp plans generated for a parallel gripper using camera images of the workspace.

2 Artificial Grid Fields in Motion Planning

Robot motion planning is known to be a very difficult problem. Most solutions rely on a search in the free configuration space (C space) of the robot which is the set of all the possible configurations of the robot regarding the obstacles in its workspace[LP82]. Determinig the free space requires complete knowledge about the device and all the obstacles in the workspace and is computationally expensive.

Artificial force fields have recently become a popular technique for robot planning (see [Kod89] for an overview), mainly for obstacle avoidance tasks. The basic idea is that an object moves according to a field of forces in order to achieve a goal[Kha86]. In this method the robot moves in its configuration space according to a potential field attracting it to the goal. The potential force at a point in configuration space is the combination of an attractive force towards the goal and a repulsive force pointing away from obstacles which are near to the point. An advantage of this method is that it only needs knowledge about the C space in the neighbourhood of the object instead of a complete a priori computation of the obstacle space. Though this method suffers from the problem of local minima which appear when attractive and repulsive forces complement each other. This has stimulated the search for potential functions without the local minima problem.

A solution to this problem has been provided in the case of a representation of the configuration space as an n-dimensional grid. A field is created by applying to this grid a *number diffusion process* starting from a goal cell labeling all free cells with its L^1 (or Manhattan) distance to this goal. We can find a shortest path from each cell to the goal, if one exists, by following the inverse of the gradient at each cell.

Because of the computational bottleneck for computing the complete free space and the fields over these usually high dimensional space, methods have been proposed that use an artificial field defined over the workspace of the device as the heuristic to guide the search in the configuration space. In these methods a field is created on the discretized workspace of the robot instead of its configuration space. The motion of the robot is simulated in the workspace guided by a number of control points positioned on the device, for which a potential can be found in the workspace field. This potential is only computed for the set of neighbour configurations of the robot and is then used to guide the search. Collision detection is done during the simulation in the workspace to discreminate unallowed configurations. In order to deal with local minima, which can exist because of conflicting attraction of the control points and because of the size and shape of the device, powerfull search techniques are necessary. Despite possible local minima this method is considerably faster than the classical C-space approach, mainly because a complete computation of the free configuration space is avoided. This technique was developed by Barraquand and Latombe and is described in detail in [Lat91]and [BL89]. In the next chapter we describe how we are going to adapt this technique in the field of grasp planning.

3 Artificial Grid Fields for Grasp Planning

In this section we describe the artificial grid fields that we use to plan the motion of a gripper to grasp an object. A significant difference with the general path planning approach is that there is not a predefined configuration defined as a goal. Instead the search must be directed to find a placement of the gripper relative to the object to obtain a stable grasp. In order to plan a path for the gripper towards the border of the target object and to guide the search for an effective grasp, we use two artificial grid fields defined over the workspace of the gripper. A first grid field expresses the attraction towards the border of the target object while a second one attracts the gripper to a focus point on the target object. This can be the center of gravity of the object or another point defined by the user. Using these fields a path is planned from the initial configuration towards the target object by a motion planner component until a grasping configuration is reached. In practice we have used an object representation model that enables an object to move in a discrete world according to a force applying on it [GH91]. This grasping configuration is then evaluated for stability according to a number of heuristics. If the grasping configuration is evaluated as not stable, the search is proceeded and control is passed to the motion planner. This process stops when a satisfying grasping configuration is found. The stability check and the motion planning using these fields are describred in detail in the next chapters.

3.1 Target object attractive field.

The field attracting the target object is obtained by a number propagating *wave* process, starting from the border of the object. This wave process avoids the obstaclesx in the workspace. First the border pixels of the objects are determined and labeled “0”, all free unlabeled neighbour pixels of these are then labeled “1”, and so on until all free pixels are labeled. As a result we obtain a field over the free pixels in the image. In this field it is possible to find the shortest collision-free path starting from a given point towards the border

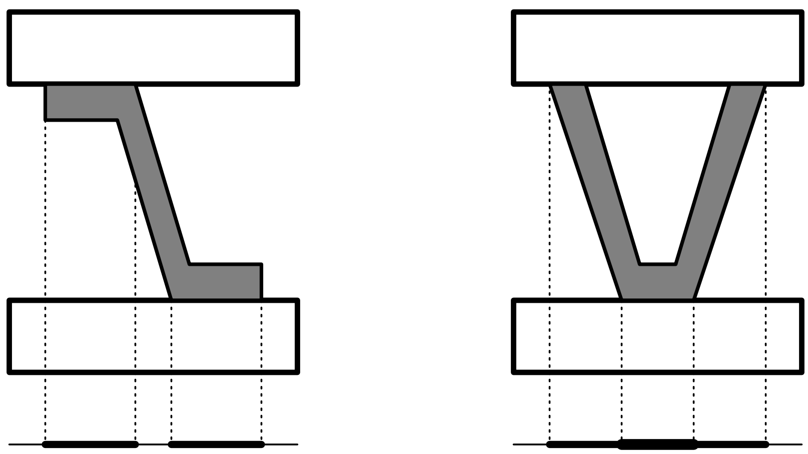

Figure 1: The stability check for a two-fingered parallel gripper.

of the object. We will use this property as a heuristic to direct the gripper towards the border of the object avoiding the obstacles. It is also possible to avoid grasping on certain parts of the object, e.g. if the material is fragile at this place, by simply marking these contour cells and deleting them from the set where the number propagation starts.

3.2 Focal point attractive field.

Starting from a given point somewhere on the objects surface, we execute a similar wave propagation process, though not avoiding the pixels of the target object but only those of external objects. This results in a field over the target object and all the free pixels in the workspace image. It attracts every point to the focal position on the target object avoiding the surrounding obstacles. This field will be used to guide the gripper as close as possible to the focal point. It will also serve to evaluate grasping configurations by favouring grasps close to the focus point.

4 Grasp Evaluation

A grasping configuration is obtained when contact is detected between the target object and the inside of the gripper fingers. This grasping configuration is then checked for stability without considering friction. A grasp is considered stable if the forces applied by the gripper fingers at the contact points does not result in a rotation or translation of the object. For a parallel jaw gripper this can be checked in an easy way. See figure 1 for an example of an unstable (fig. 1.a) and a stable grasp (fig 1.b). In this case, the force applied at a contact point is perpendicular to the finger and directed towards the inside of the gripper. For this reason there can be no translation of the object along the perpendicular axis. In order to check if there is a torque we first determine the area of contact on each finger. This is the line between the extreme contact points on the finger. If the projections of these areas on a line parrallel to the gripper fingers have a common intersection, we can be sure that the torque is zero and the grasp is considered to be stable. Figure 1.a shows a situation in which there is no intersection between the projections, this will result in a torque. Figure 1.b shows a situation where there is an intersection between the projections of the contact areas. This is considered to be a stable grasp.

5 Gripper Motion Planning

A configuration of a gripper q as used in the examples (see figures 2,3 and 4) to illustrate our method is determined by 4 parameters, i.e. the x and y position of the gripper in the plane of the object silhouette, the orientation θ of the gripper and the distance d between the fingers which is constrained by some maximum value. A collision-free path, which is a list of configurations starting from an initial gripper configuration q_{init} and resulting in a grasp configuration q_{grasp}, is found by simulating the motion of the gripper in the workspace image according to the artificial attractive fields defined over it. After the complete path is obtained by this simulation it can be executed by the robot in the real workspace.

The simulated motion of the gripper in the workspace is guided by a number of control points $c_1 ... c_n$ attached to the grippers surface. A control point is positioned in a cell of the grid and has a potential value V_c which is a combination of the cells values in the border attractive field V_b and the focal point attractive field V_f:

$$V_c(c_i) = \eta V_b(c_i) + \mu V_f(c_i)$$

in which η determines the weight given to the border field and μ the weight given to the requirement of being close to the focal point. Each configuration of the gripper g has a potential value V_g which is the combination of the values of its control points.

$$V_g(G) = \sum V_c(c_i)$$

We use this value to guide the search in configuration space to find the path for the gripper towards the target object. It is not necessary to compute the potential value for all the configurations but only for those that are necessary for the search. For a given configuration the potential value is computed only for its neighbours in configuration space (i.e. by making small changes for every degree of freedom). From all these we chose the configuration with the smallest potential value and we simulate this in the workspace to check wheter it is collision free. If not, we take the next smallest until we find a collision-free configuration. From this a new search step is started until a grasping configuration is found. It is possible that during the search local minima are encounterd, i.e. when no neighbour configuration with a lower potential exists. In this case a backtracking mechanism must be used. How different search strategies can solve this problem is explained in a following chapter.

6 Search Strategies

The main strategy used during the gripper motion planning is the best first search with backtracking from local minima (see [Pea84] for an overview of search techniques using

Figure 2: Three stable grasps for a planar object.

heuristics). We have extended this stategy with some ad hoc methods adapted to the problem of grasping. A first feature is that we decrease the step of moving the gripper as we come closer to the target object, i.e. we will start by making relatively big steps towards the target object avoiding the possible obstacles and end by very small changes of the gripper configuration in order to match the fingers to the object contour.

In this way we execute a best first search in order to plan a path towards a stable grasp configuration. In general we will not limit the search to one satisfying grasp. Because we plan by simulating the motion of the gripper using a silhouette of the object which can contain errors because of shades we will try to find a set of stable grasps. After a first stable grasp is found by a best-first strategy, all the configurations close to this one are investigated in order to find other possible grasps. When this local exhaustive search is finished, a retraction strategy can be executed by taking the neighbour configuration with the highest potential is chosen as the next. In other words, the fields become repulsive in stead of attractive. This lasts for a number of steps and results in a gripper configuration with a maximum distance between the fingers. From this configuration we restart a best-first stategy until a new grasp is found. From experiments we have concluded that in this way a better grasp, i.e. one that is closer to the focal point, is found in a faster way than using an exhaustive best-first method.

Though this method usually finds a solution quite fast, it is possible that for a given initial position no solution is possible because of the chosen discretisation or because a path simply does not exist. By chosing a higher density for the discretised configuration space and workspace it sometimes is still possible to come to a solution. In practice it is often recommended to change the initial configuration of the gripper if the search process takes too long. The motion planning method with artificial grid fields described in [Lat91] describes a search stategy with randomized motion in case of local minima. This proves to be an effective method in the case of very cluttered workspaces and for this it can be used for planning the initial motion of the gripper, i.e. for bringing the hand close to the object.

7 Results

We have implemented our method using a simulation of a two-fingered parallel gripper grasping in a two dimensional plane. As the workspace for this gripper we have used some real camera images which we have mapped onto a discrete grid. Figure 2 shows three stable grasp configurations obtained by our method applied to a bitmap representing a planar object without considering obstacles. The white dot on the object denotes the center of mass which acts as the focus point of attraction for the gripper. The solution found in figure 2.b is the stable grasp closest to this point. Notice that this solution could not be found by regarding the contacts as points or by looking for parallel faces of the objects. In figure 3 some solutions for grasping a peg are shown. The first figure shows the camera image of a workspace with several pegs and holes. The gripper is supposed to move in this two dimensional plane and grasping the peg in the center thereby avoiding the other pegs around it. Figure 3.b shows a solution when the gripper is initially placed over the peg. The fingers are simply attracted by the contour and near to the center of the peg. In figure 3.c the starting configuration is far away from the target and the gripper has to navigate between the obstacles in order to grasp the target. Figure 3.d shows a solution for another starting configuration. Figure 4 shows two solution paths for grasping another kind of object starting from the same position. The second path (figure 4.b) is found faster by chosing a more fine grained discretisation of both the warkspace and the configuration space.

8 Conclusion

In this paper we have shown how path planning techniques based on artificial fields can be applied to plan the motion of a gripper towards an object hereby resulting in a stable grasp. Having experimented with the method by simulating the grasping of planar objects using camera images we are convinced about the applicability of the method for more complicated grasping problems. We are currently integrating the system with a real robot arm and gripper. Exploiting the current state of the art in robot vision we will be able to extend the method for arbitrary objects in a 3D workspace. The grid fields that have been defined direct the path search towards a stable grasping configuration. For this we have developed a number of appropriate stategies which can be improved, e.g. it could be adapted to deal with an artificial hand.

The main advantage of the system is that the difficult problem of planning the collision free motion for a gripper is treated as a priority and in an effective way. The use of simulation in the workspace avoids the need for the computation of the complete free space which is a time-saving advantage over traditional planners.

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Figure 3: Examples of grasp plans for a gripper using camera images.

Figure 4: Two grasps for an object using different discretisation in the search space

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