A FLEXIBLE TACTILE GRASPING STRATEGY FOR AUTONOMOUS ROBOTIC DISASSEMBLY

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ABSTRACT

One of the central problems of autonomous robotic disassembly is grasping the object to be disassembled which is generally located inside a complex arrangement, so that in most cases - particularly for electronic products - the parts are hardly accessible. In this paper, a flexible tactile grasping strategy for an autonomous robot system equipped with a multi-sensory parallel-jaw gripper, a laser range finder and a wrist force-torque sensor will be presented. The strategy is flexible regarding the objects to be grasped even under uncertain state conditions, because only few modelling is required. Grasping points which are only coarsely known and hardly accessible can be reached and a stable grasp is established by tactile dexterity. Practical experiments have been carried out e.g. for the complex problem of grasping the objective module inside a camcorder.

1 INTRODUCTION

Disassembly is becoming an interesting problem and a great challenge in automation, not only for environmental reasons but for economical reasons as well. One of the central problems of autonomous robotic disassembly is grasping the object to be disassembled which is generally located inside a complex arrangement, so that there is often a lack of clearance. Particularly, in electronic products with their compact construction, the single parts or components are only hardly accessible. Furthermore, a secure and stable grasp is important with regard to the high forces usually arising during the subsequent disassembly operation.

However, disassembly cannot be considered generally as the reversal of assembly because the condition of the product to be disassembled may change during its life-cycle, e.g., due to aging, use or product repair. As a result of this raised uncertainty, object models based on the product state of assembly cannot be used unrestrictedly for the disassembly of end-of-life products or they are often not completely available. Therefore, flexible sensor-based strategies have to be applied for grasping and disassembling end-of-life products.

There exist a lot of approaches for grasp and motion planning in literature (e.g., Latombe 1991, Lozano-Pérez et al. 1992, Viete 1993), but in most cases they are based on geometric reasoning only requiring an exact modelling of the environment. In disassembly, however, flexible grasping strategies should not depend on an exact modelling of the environment due to the high uncertainty. Moreover, a fundamental problem in disassembly is approaching and grasping objects under uncertainty and difficult accessibility, i.e., grasping objects out of a complex assembly, which has been little investigated, up to now.

Therefore, in this paper, a flexible tactile grasping strategy for an autonomous robot system equipped with a multi-sensory parallel-jaw gripper, a laser range finder and a wrist force-torque sensor will be presented (see fig. 1). The strategy is flexible regarding the objects to be grasped even under uncertain state conditions, because only few modelling is required. Particularly, grasping points which are only coarsely known and hardly accessible can be reached and a stable grasp can be established by tactile dexterity.

![Figure 1: Experimental set-up: robot system consisting of a 6-axes robot arm with a laser range finder, a wrist force-torque sensor and a multi-sensory parallel-jaw gripper which has been developed at the Department of Control Systems Theory and Robotics.](image-url)
In the next section, after a brief description of the applied grasp planning approach, the tactile grasping strategy and its realization by a fuzzy approach will be explained. Finally, the results from laboratory experiments carried out for the complex problem of grasping the objective module inside a camcorder will be presented followed by some conclusions.

2 GRASPING STRATEGY

The tactile grasping strategy to be presented in the following has been developed for parallel-jaw grippers. Since the disassembly of technical products in most cases requires handling of rather regularly shaped objects, it is sufficient to use a parallel-jaw gripper for grasping. However, handling objects of the daily life, e.g., grasping a watering-can (see e.g. Seitz et al. 1995), often requires multi-fingered grippers.

2.1 Grasp Planning

Before approaching an object for grasping and disassembly, the planning of a suitable grasp has to be performed. In (Weigl et al. 1995) an approach was presented for searching and localizing suitable gripping points on arbitrarily shaped objects using sensor images acquired by a laser range finder (cf. fig. 1). For sensor image processing the range data are represented in a 2D gray level image without losing 3D information. Interpreting the depth as a gray tone allows the reduction of the relevant image information to edges describing object areas of different height. In particular, suitable gripping points have to be determined providing enough clearance and a sufficient grasp depth in the area around each contact point for immersing the parallel-jaw gripper into the product to be disassembled. While the clearance is necessary for the immersing operation itself, a sufficient grasp depth is essential to provide a stable grasp which is indispensable for the disassembly operation to be performed.

The grasp planning approach could further be improved by applying a combination of video (color) image processing and range image processing. Especially if the scene to be analyzed is very large, a kind of pre-segmentation by video image processing is reasonable in order to determine a region of interest which, subsequently, will be scanned by the laser range finder, possibly with maximum resolution.

2.2 Tactile Strategy, Situation Clusters and Corresponding Motion Rules

As already mentioned in the beginning, the tactile grasping strategy developed in this work, requires only a coarse determination of suitable gripping points planned e.g. by the approach described above. According to these gripping points a coarse approaching direction is specified as a global motion for the robot system. The fine motions to be superposed to the global motion during the approaching and grasping process – in the following also called immersing operation – are then planned online based on the actual force-torque sensor information supplied by a wrist force-torque sensor. In this way, no exact model of the environment is necessary and the system is robust against uncertainties.

The tactile grasping strategy allows the robot system to act in a way similar to the human behavior solving the problem of immersing, e.g., into an electronic product to be disassembled, in order to grasp hardly accessible objects located inside. For that, it is necessary to specify typical situations occurring during the immersing operation and to determine the corresponding way of acting, i.e., motion rules for the robot system. In addition to this, the system has to classify the different situations into clusters, so that it is possible to abstract from the specific situation to a basic problem, for which a corresponding way of acting has to be specified. These clusters are characterized by the degrees of freedom of the robot system in the respective situation and can be determined quite well on the basis of the external forces and torques experienced by the robot end effector, which is the parallel-jaw gripper in our case.

In the following, the principal situation clusters (cf. fig. 2) and the corresponding motion rules for the robot system will be presented for a sample immersing process. Supposing the gripper is in a starting position above the object to be grasped, the gripper opening width is adapted and the approaching motion in the immersing direction can be started. In the beginning, if the measured forces and torques are about zero, the system is in the so-called \(<free\ space>\) cluster. The \(<free\ space>\) cluster includes all situations in which the measured forces and torques are about zero, i.e., the gripper is freely movable, as shown in fig. 2a, and consequently, the movement in the global immersing direction can be continued.

| IF the system is in the \(<free\ space>\) cluster, THEN continue movement in the global immersing direction. |

However, this ideal system state will change during the further immersing process, for example due to the difficult accessibility or other uncertainties. As soon as the system detects a contact with the environment, the previously specified straight immersing movement to the desired grasp depth cannot be continued. Then, the gripper jaws are not sliding along both lateral faces of the respective object, but very often the gripper will strike on the top face of the object with one of its jaws. In case of this so-called \(<striking\ on\ the\ object\ with\ one\ gripper\ jaw>\) cluster, a lateral displacement has to be compensated by the robot as shown in fig. 2b. The direction of the necessary strategy motion along the z-axis depends on the sign of the torque about the y-axis experienced by the gripper. Furthermore, before starting the lateral correcting motion, it is advisable to lift the gripper in order to avoid scraping on the object.
IF the system is in the <striking on the object with one gripper jaw> cluster, THEN lift the gripper and correct the lateral displacement according to the experienced torque.

At any rate, this motion rule assumes that the gripper strikes on the top face of the object with one of its jaws, but not on the top face of other parts, for example the casing. In this case, a correcting motion in opposite direction as described above has to be executed. Due to the fact, that distinguishing between these situations is not possible based on the experienced forces and torques only, it has to be guaranteed, that the gripper always strikes on the top face of the object. Usually, this can be achieved by a proper adjustment of the gripper opening width. For that purpose, in the beginning of the immersing process the gripper opening width is substantially smaller than the width of the object to be grasped. If the gripper is now moving down from its starting position, first of all, it will strike on the top face of the respective object despite a possible displacement from the center. Possibly, it is even necessary to approach the object with closed gripper jaws in order to guarantee this situation. This as well as the lateral correcting motion lead to a situation cluster, in which both gripper jaws are striking on the object (cf. fig. 2c). In the so-called <striking on the object with both gripper jaws> cluster, the gripper opening width is increased step by step until at least one gripper jaw could pass the object and the system is again in the <striking on the object with one gripper jaw> cluster. Each step for increasing the gripper opening width should not be larger than the thickness of the gripper jaw, otherwise the immersing strategy may fail. Increasing the gripper opening width will not only take place in case of striking on the top face of the object, but also during the further immersing process, if the object is widening from top to bottom. In both cases, the gripper opening width has to be adapted to the object width. Again, it is advisable to lift the gripper before increasing the gripper opening width in order to avoid scraping on the object.

IF the system is in the <striking on the object with both gripper jaws> cluster, THEN lift the gripper and increase the gripper opening width.

If the gripper opening width has been adapted and the object is almost centered between the gripper jaws by the lateral correcting motion, the immersing motion can be continued. All other situations not contained in one of the clusters specified above are combined in a so-called <any other situation> cluster, in which evading movements according to the experienced forces and torques are executed. This <any other situation> cluster comprises situations like scraping of a gripper jaw on the lateral face of the object or the casing as shown in fig. 2d as well as possible orientation errors.

IF the system is in the <any other situation> cluster, THEN execute evading movements according to the experienced forces and torques.

This passive way of acting has been chosen in order to avoid damage to the disassembly object. By introducing the <any other situation> cluster a kind of completeness for the system behavior is achieved, i.e. for every situation a corresponding motion rule is specified. The break-off criterion of the immersing strategy is either reaching a desired grasp depth in case of success or exceeding the maximum time. However, using a local strategy always involves the risk that the strategy gets into cycles and in this case an additional global strategy is required in order to execute e.g. random movements and/or global searching motions.

\[\text{Randomization has been proven to be an useful primitive in the solution of robot tasks (cf. e.g. Erdmann 1990).}\]
2.3 Realization by a Fuzzy Approach

For implementing the motion rules of the grasping strategy, a fuzzy approach was used leading to smooth transitions between the different situation clusters as well as to an easy man-machine interface. Considering disturbances involved in the measured force-torque data, by fuzzification of the measured values and corresponding determination of the membership functions, an additional filtering of the force-torque data, always causing time delay, is not necessary and the system reacts promptly to the sensor information. A superposition of the situation clusters and consequently of the corresponding motion rules can easily be realized. The resulting controller generating the nominal velocities in order to command the robot motion is shown in fig. 3. Input variables of the controller are the force and torque error $df$ and the global immersing motion $w$, output variables is the nominal velocity $v$. Input and output variables are represented as linguistic variables with three different terms negative, about zero, positive using membership functions as shown in fig. 4. Based on the external forces and torques experienced by the robot end effector, which is the parallel-jaw gripper in our case, the different situations are classified into the clusters with their corresponding generic motion rules presented above. Therefore, the resulting rule base consists of various rules of the following form, e.g.

If $(df_x$ is about zero) and $(dm_y$ is positive) and $(dm_z$ is about zero) and $(v_{trans,x}$ is about zero),
THEN $(v_{trans,x}$ is positive).

or

IF $(dm_z$ is positive) and $(df_x$ is about zero) and $(df_y$ is about zero) and $(w_{rot,z}$ is about zero),
THEN $(v_{rot,z}$ is positive).

These two examples of possible rules represent situations of the <striking on the object with one gripper jaw> cluster (cf. 2b) and of the <any other situation> cluster.

In addition to commanding the robot, the adaptation of the gripper opening width is determined and performed in parallel to the robot motion. After successfully immersing and approaching the object a stable grasp is established and the object can be disassembled. For the subsequent disassembly operation a force-torque sensor-based strategy has been developed (Weigl and Holm 1995) similar to the presented tactile grasping strategy. The underlying overall control structure for flexible autonomous robot motions distinguishing between global and local motions is described in (Weigl et al. 1996).

3 EXPERIMENTAL RESULTS

Practical experiments have been carried out for a simple block-in-a-box task as well as for the complex problem of grasping the objective module inside a camcorder. The results document that the immersing strategy basically works. Fig. 5 shows the graphs of the actual forces and torques, the actual gripper opening width, the global immersing velocity, the nominal velocity generated by the non-linear mapping-based controller as well as the actual translational position of the robot end effector during the immersing operation into a camcorder in order to approach and grasp the objective module which is hardly accessible. The difficulty is, that there is not much clearance inside the camcorder for immersing with the gripper jaws, only a few millimeters around the possible gripping points. In order to prove the efficiency of the tactile immersing strategy a translational error of about 25mm in x-direction (cf. fig. 2b), the moving direction
Figure 5: Immersing operation for approaching and grasping the objective module located inside a camcorder: (a) actual forces and (b) actual torques (in task coordinates $[O]$), (c) actual gripper opening width, (d) global translational immersing velocity (in base coordinates $[B]$, normalized), (e) nominal translational velocity (in task coordinates $[O]$, normalized) generated by the non-linear mapping-based controller and (f) actual translational position of the end effector.
of the gripper jaws, was produced for the starting position above the object, although naturally the grasp planning approach described in section 2.1 is much more accurate.

First of all, in the starting position the gripper jaws are nearly closed (gripper opening width is 25mm, see fig. 5c) and then, the approaching motion in the global immersing direction (cf. fig. 5d) can be started. After about 10sec the gripper has moved down about 60mm in z-direction (cf. fig. 5f) and now, it strikes on the top face of the object with one of its gripper jaws (see the force in z-direction in fig. 5a and the torque about the y-axis in fig. 5b). In the following, the lateral displacement is corrected by moving in negative z-direction (cf. fig. 5f) always lifting the gripper a little bit in order to avoid scraping on the object. After about 30sec the lateral displacement of about 25mm has been almost compensated and then, the gripper strikes on the object with both of its gripper jaws. Now, the gripper opening width is adapted to the object width by increasing the gripper opening width step by step (cf. fig. 5c) until after about 40sec, the gripper jaws can slide along both lateral faces of the object and the motion in immersing direction can be continued. If a sufficient grasp depth for the gripper jaws has been reached – in this example after further immersing 45mm in z-direction (cf. fig. 5f), thus a total translation of 115mm in z-direction – the object is grasped and can be disassembled. During the immersing process e.g. also small translational errors in y-direction had to be compensated (cf. fig. 5a and fig. 5f) as well as small rotational errors about the z-axis (cf. fig. 5b). By optimizing the strategy parameters the overall system performance can still be improved and the necessary strategy time can be reduced.

Provided that the gripper actually strikes the object to be grasped, the local strategy can easily cope with large translational errors in z-direction. In case of starting the strategy with closed gripper jaws, translational errors up to half the object width can be compensated. For translational errors in y-direction it is a more difficult problem, because if the displacement is too large, so that it is not possible to immerse at least into the desired, coarsely specified grasping area, the strategy may fail or the gripper immerses into another area if possible. In this case, the strategy cannot overcome the error situation, because it is only a local strategy without the ability of actively inspecting its environment and therefore, an additional global strategy is necessary in order to execute global searching motions. Considering those restrictions the success rate of the practical experiments was 100% for about 50 trials. The immersing strategy was also able to compensate orientation errors of about 40 degrees.

4 CONCLUSIONS

In this work, a flexible grasping strategy based on tactile dexterity has been developed for an autonomous robot system equipped with a parallel-jaw gripper, a laser range finder and a wrist force-torque sensor. The tactile strategy is flexible regarding the objects to be grasped even under uncertain start conditions, because only few modelling is required. Practical experiments have been carried out, e.g. for the complex problem of grasping the objective module inside a camcorder, documenting that the strategy basically works. The implementation of the strategy was realized by a fuzzy approach leading to smooth transitions between the different situation clusters on the one hand and to an easy man-machine interface on the other hand. Since this sensor-based immersing strategy is only a local strategy, it has to be provided that, despite errors and uncertainties, the gripper actually strikes the object to be grasped. In order to further extend the applicability of the tactile grasping strategy, a global searching strategy, possibly based on additional sensor information by a vision system, has to be integrated.

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REFERENCES


