Using A Multisensory Gripper System For Robot Assisted Disassembly Of Electronic Devices

Karlheinz Hohm[(1)], Alexandra Weigl[(1)], Bernd Krüger[(1)], Matthias Schwartz[(2)], and Henning Tolle[(1)]

[(1)] Darmstadt University of Technology, Control Systems Theory and Robotics Dept.,
Landgraf-Georg-Straße 4, D-64283 Darmstadt, Germany
Phone: ++49-6151-16-7402, Fax: ++49-6151-293604
e-mail: hohm@rt.e-technik.tu-darmstadt.de

[(2)] Zentrum für Neuroinformatik, Gesellschaft für intelligente Informationsverarbeitung mbH
Am Botanischen Garten, Universitätsstraße 160, D-44801 Bochum, Germany

Abstract

This paper presents a multisensory parallel jaw gripper system for complex object manipulation purposes of an autonomous robot disassembly system. The jaws of the gripper integrate different types of sensors. First an optical array of pulsed IR-diodes enables detection of object presence between the gripper jaws. Furthermore, a tactile matrix sensor is integrated, measuring contact force distribution over its surface using conductive rubber. It provides the system with information about the quality of an established grasp, the resulting normal grasp force, and it can be used for slip detection of the object, which is the most important use of tactile sensors during object manipulation. Therefore, a respective fast and simple method is presented with experimental results proving its reliability.

1 Introduction

Considering the already very high but still increasing number of end-of-life products especially in the area of electronic devices, non-destructive disassembly and re-use of valuable modules is one possibility to face this problem in an environmentally sensible way. For economical reasons due to the resulting quantity of products to be recycled as well as for safe working conditions for human workers increasing automation of disassembly seems to be indispensable. However, disassembly can not generally be considered as the reversal of assembly due to modifications by means of repair or damage during use of a device. This causes a rather high degree of state uncertainty so that assembly models, if available at all, can only be used as a rough base for disassembly planning. The final global and local planning of a system for automated or at least semi-automated disassembly must be based on sensor information acquired from the actual device. Therefore, in contrast to automated assembly of products in an industrial environment the use of multisensory systems is of evident necessity for disassembling the same products at the end of their life cycle (see e.g. [Dario et al. 94], [Weigl 94]).

While in global disassembly planning sensor systems, as e.g. vision systems, are very useful, in local planning operations tactile information is of foremost importance to enable autonomous complex object handling by a robot system. Especially in the context of electronic devices the compact construction causes continuous changes of the contact situation between the object to be disassembled and other modules inside the device and/or the casing. Nevertheless, we could show that already indirect tactile information provided by a force/torque sensor, mounted at the wrist of the robot, enables autonomous grasping and disassembly operations by a flexible robot system equipped with a parallel jaw gripper (see [Weigl, Schwartz, Bettenhausen 96], [Weigl, Hohm, Tolle 96]). But the overall behavior of the system can further be improved by using direct tactile sensors integrated into the gripper jaws of the parallel jaw gripper. The new gripper jaws of the multisensory gripper system we present in this paper are designed for this purpose and therefore integrate different types of sensors useful for autonomous object manipulation.

In section 2 some related papers about tactile sensors and especially about methods for slip detection, which is the most interesting use of tactile sensor systems during object manipulation, are reviewed. Section 3 presents our gripper system and section 4 describes the operation of the whole system with a detailed discussion of our method for slip detection. The paper ends with conclusions and an outlook on future work.

2 Related Work

While most force/torque sensors provide only indirect tactile information during the manipulation of an object also direct tactile information is necessary (for discussion see e.g. [Howe 94]). Therefore, grippers should include tactile sensors as for example presented in [Seekircher, Hoffmann 88], [Maekawa et al. 92] or [Holweg 96]. Due to the spatial arrangement of the single tactile elements (taxels) in the newer sensors as a matrix these direct tactile sensors can give three types of information. First they give an idea of the quality of an established grasp by the activated taxels, during the manipulation they can be used for detecting slip of an object, and last but not least they measure the resulting force applied to the object for grasp force control.

During object manipulation the most important use of direct tactile sensors is for slip detection, because of jamming and wedging of the object during the manipulation process due to contact with other objects in the environment it may get out of the gripper. This problem can be detected very early by detecting the slip of the object within the gripper so that suitable measures can be taken to keep the grasp stable and so to overcome critical situations of this type.

Some existing approaches for slip detection with tactile sensors are based on information acquired by different sensors integrated into one tactile "multi-sensor". They measure e.g. the micro-vibrations by a dynamic sub-sensor or do a combination of the dynamic information with force analysis (see e.g. [Howe, Cutkosky 89], [Tremblay, Cutkosky 93] or especially [Mingrino et al. 94]). These micro-vibrations are caused by the stick-slip-effect, when the object periodically moves a little bit by tangentially deforming the elastic sensor surface until the sensor surface comes off the object and snaps back.

Other approaches are based only on force information and perform e.g. a frequency analysis of measured force values (see e.g. [Marconi, Melchiorri 96] or [Holweg et al. 96]). Because tactile sensors provide the resulting normal force as well as the center of the contact point both informations can be used. In case of a fourier transformation of the resulting normal force one can detect the start of slipping by the short appearance of a dominating 10Hz peek. Slipping itself leads to a 65Hz peek which is characteristic for the stick-slip-effect. During supervising the center point of the contact as long as no slipping occurs only noise can be found in the spectrum but immediately before slipping starts the low frequencies components become dominant.

The disadvantage of all these approaches is that either a highly integrated "multi-sensor" is necessary, which can hardly be found regarding the required robustness and miniaturization necessary in the context of disassembly, and/or a high amount of computing power is needed. Thus we propose a fast and simple method for slip detection during object manipulation based on normal force prediction.

3 The Multisensory Gripper System

Figure 1 shows the multisensory parallel jaw gripper system we designed for manipulation purpose. On the left (see fig. 1a) the whole gripper is shown. On the base-plate a six degree of freedom force/torque sensor is mounted, which provides the system with indirect tactile information. Above it is the parallel jaw gripper itself which has a position sensor for control of the opening width. The jaws integrate different types of sensors (see fig. 1b). First an optical array of infra-red (IR) sensors, consisting of pulsed IR diodes with detectors on the opposite jaw. It is used to detect the presence of an object between the gripper jaws. Experiments have shown that an array of only six elements is sufficient in most cases. The fact that they work in the IR spectrum makes the system robust against normal daylight as well as neon light as it is used in industrial environment. Controlled pulsing of the sensor system further increases this robustness.

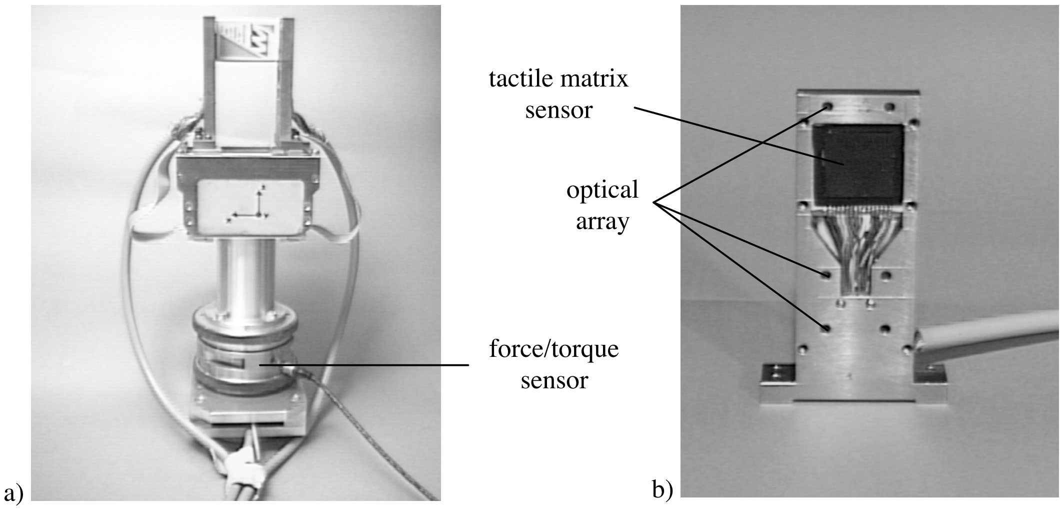

Fig. 1 The multisensory gripper system. On the left the whole gripper system is shown, grasping a match box. On the right a single gripper jaw with its optical array and the tactile matrix sensor is shown.

Also a tactile matrix sensor (TMS) is integrated. It consists of a 16×16-matrix of tactile force sensor elements on an area of 20×20 mm^2, measuring contact force distribution over its surface using conductive rubber. It is connected to the host computer of the gripper system via an interface box which allows preprocessing of the acquired data like e.g. computing the center of the force distribution or the resulting normal force. It provides the system with three types of information:

- The force distribution over the sensor taxels gives an idea of the quality of the established grasp by the surface of contact between gripper jaws and object, because the more taxels measure a contact force the more stable is the grasp. This way the tactile sensor image can be used for characterization of an established grasp direct after grasping an object and also later in the disassembly process if necessary.
- During object manipulation the information is used for slip detection, because due to jamming and wedging of the object during the disassembly process it may slip out of the gripper. This problem can be detected very early so that suitable measures can be taken to overcome critical situations of this type. In the case of heavy slip of the object, causing bigger moving within

the gripper jaws, of course also the optical array mentioned above can be used for slip detection by watching the on-/off-switching of array elements.

- Last but not least the computed resulting normal force is used for grasp force control.

This way it is possible to have a fast simple grasp force control loop at the low level control and an evaluation of more detailed tactile information on a higher level supervisory control loop.

4 System Operation

In object manipulation two phases can be distinguished, first approaching and grasping of the object and second the manipulation itself. Both phases are supported by the sensors integrated into the gripper system.

4.1 Approaching and Grasping of an Object

For localizing an object to be manipulated in most cases vision systems or range finders are used. They provide quite good information which can be used for grasp planning. Nevertheless, there are still some uncertainties especially if the addressed object is e.g. partially hidden and/or no optimal illumination is possible, because the object is among others and/or in a casing as it is in the context of disassembly. Then the gripper has to immerse into the casing and tactile information can help to overcome these state uncertainties and support establishing a stable grasp at the object. During approaching the object the optical array of IR sensors is used to detect whether the object is within the gripper jaws. As soon as the 1st row of the array detects the object the immersing phase starts. If the object is not centered between the gripper jaws so that slight collisions of the gripper and the object occur, the information provided by the 6DOF force/torque sensor can be used for tactile immersing without destroying the object. The 2nd row of IR sensors indicates that a sufficient grasp depth has been reached. From now on further immersing is only for increasing the stability of the grasp by enlarging the contact surface. It has to be stopped if either the 3rd row of IR sensors indicates that the end of the gripper jaws has been reached or if the force/torque sensor measures a force indicating that the top of the gripper jaws have reached the bottom. This way a robot system is able to approach an object autonomously during the grasping process to reach the desired grasp position even in the case of uncertainties.

Next the grasp is to be established. Besides the control of the desired grasp force also the "quality" of the grasp is of interest to characterize its stability. Due to the spatial arrangement of the single taxels of the tactile sensor as a matrix, a very simple but already effective method is counting the number of activated taxels, because the more taxels detect a contact force the more stable is the grasp. However, the sensor can further measure the force at each taxel so that the force distribution over the sensor taxels gives an improved idea of the quality of the established grasp by the surface and the intensity of the contact between gripper jaws and object. This way the tactile sensor image can be used for characterization of an established grasp directly after grasping an object and also later during the manipulation process if necessary. Figure 2 shows two tactile images where a relative force distribution over the sensor surface of 16×16 taxels is illustrated (the normal force of each taxel is measured with respect to the maximum force at the current sensitivity level). In fig. 2a) a contact to a rather flat object surface is shown. Nearly the whole sensor has contact to the object and there is no special peek indicating an irregular force distribution. The contact situation in fig. 2b) is typical for grasping an cylindrical object or grasping an object at a ledge. In the latter case sometimes the quality of the grasp can be

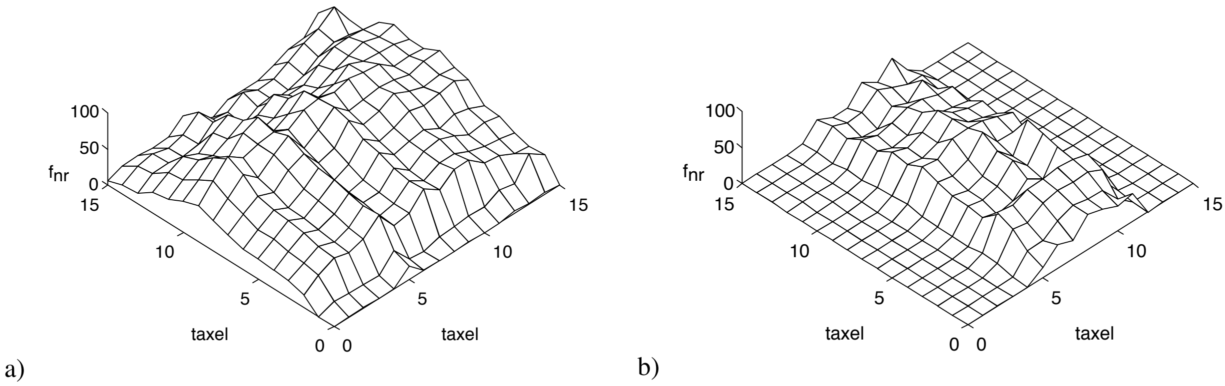

Fig. 2 This Figure shows two tactile images of the TMS, where a relative force distribution over the sensor surface of 16×16 taxels is illustrated. Fig. 2a) shows a contact to a rather flat object surface, while the contact situation in fig. 2b) is typical for either a cylindrical object or an object grasped at a ledge.

enhanced. If e.g. the gripper approached an object as described above, the space between the 2nd and the 3rd row of the optical array can be used to move back while periodically grasping the object and using this touch information to find a better grasp position somewhere before the ledge.

4.1 Manipulating an Object

During the object manipulation first of all the gripper system is used for grasp force control of the resulting normal force of the tactile sensors. Because the resulting normal force is already computed by the interface box, this control loop is very fast. Besides this also the quality of the grasp can be supervised. Due to the fact that transmitting a whole tactile image via the interface box of the TMS to the host computer takes some time, this is either performed with a rather high sampling time or only if there is some reason indicating that the contact situation has changed.

One reason which could cause a change of the contact situation is slip of the object within the gripper due to collisions with other objects in the environment. Figure 3 shows the results of an artificial experiment. The starting situation is that a robot approached and grasped an object as described above. After about 100 sampling steps (sampling time is 50ms) the robot starts to move up with constant velocity. Because the object is fixed to the table it slips out of the gripper. This situation is reached after about 400 sampling steps.

While fig. 3a) shows the movement of the robot relative to the starting position, the other three figures show measurements of the TMS of one gripper jaw. Figure 3b) presents the relative resulting normal force within the center point of the force distribution. Important is the immediate decrease of the normal force as soon as the slip of the object starts. This is a characteristic effect which can be used for slip detection. The diagrams in fig. 3c) and 3d) show how the center of the normal force distribution changes in taxel coordinates with the origin in the middle of the sensor. While in x_1 direction, which is perpendicular to the direction of the movement, only a very noisy signal appears, in direction of the movement (x_2) beginning at about sampling unit 300 the center of the force distribution moves to the end of the sensor, due to the object slipping out of the gripper.

With these results it looks very promising to use the decrease of the normal force as a simple indicator for the start of slipping. A simple difference between two sampling values would be

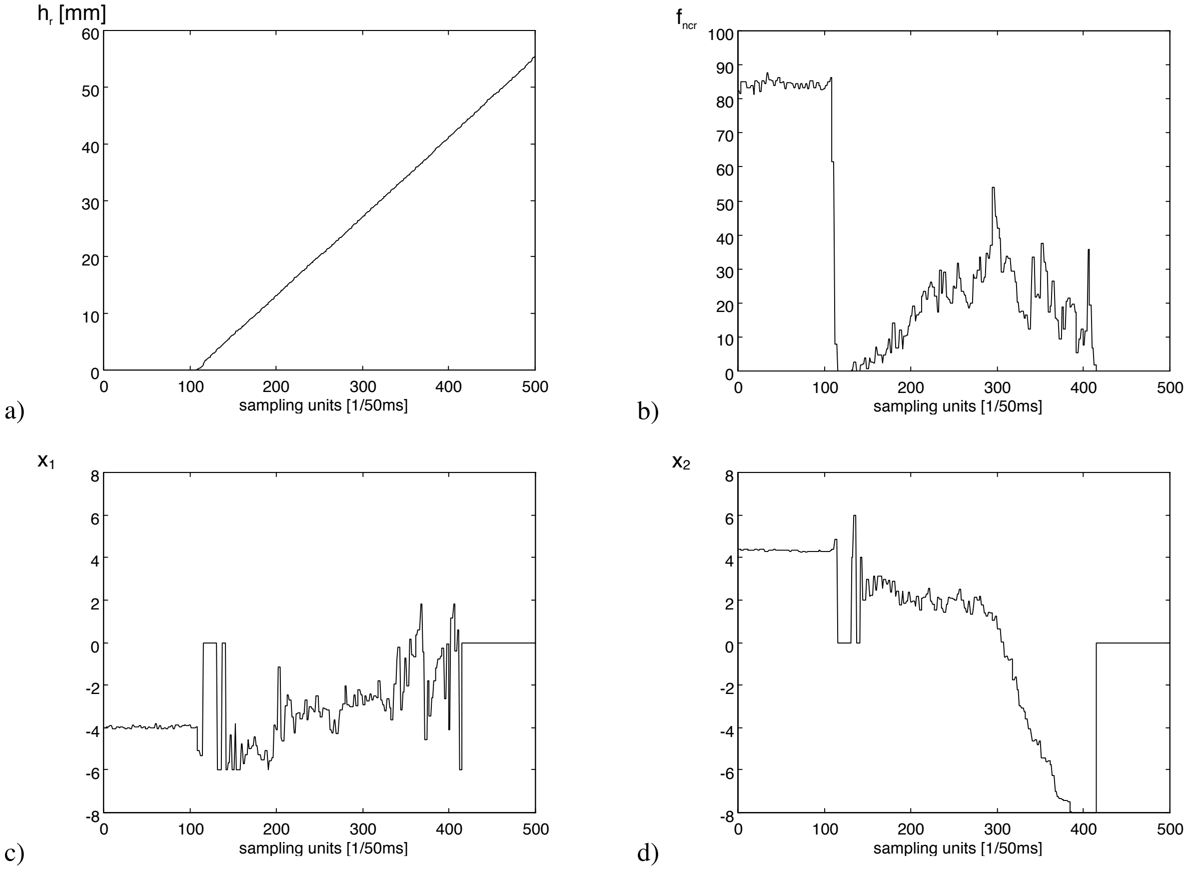

Fig. 3 The diagrams illustrate the measurements in an artificial experiment with a fixed object slipping out of the moving gripper. In fig. 3a) the movement is shown, while fig. 3b) shows the resulting normal force measured by the TMS of one gripper jaw and fig. 3c) and 3d) illustrate the center point of the force distribution in taxel coordinates.

sufficient, because during the whole movement there is no second decrease of the normal force as high as the one when slipping starts. However, the question is whether this is also possible with interference of external forces to the object due to slight collisions with other objects during the manipulation.

To get the detection algorithm more robust we suggest the following steps:

1) filtering of the measured values of the resulting normal force f_{ncr} by a median filter:

$$f_{med}(i) = \text{median}(\ f_{ncr}(i), f_{ncr}(i-1), \ldots , f_{ncr}(i-n)\ )$$

2) recursive prediction of the current value of the normal force based on the last measured value of the resulting normal force and the last predicted value f_p:

$$f_p(i) = K * f_{ncr}(i-1) + (1-K) * f_p(i-1)$$

3) slipping starts if:

$$f_p(i) - f_{med}(i) > \Delta$$

with Δ as a suitable threshold.

This allows to improve robustness of the detection but on the other hand increases the delay time arising between start of slip and detection. With the choice of n one has to be very careful not to eliminate the slope, when the normal force is decreasing, thus n should not be greater than 5,

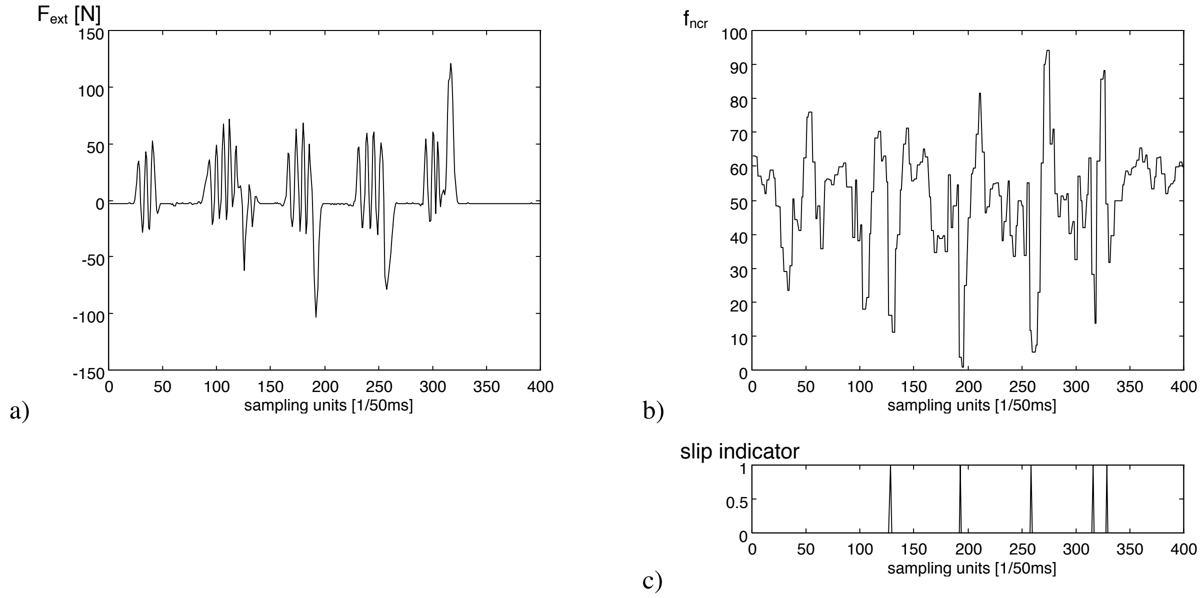

Fig. 4 The diagrams show the detection of slip due to collisions of the object. Fig. 4a) shows the external force to the object measured by the force/torque sensor and fig. 4b) its influence to the resulting normal force measured by the TMS. In fig. 4c) the results of slip detection is shown, slip is detected if slip detector = 1.

whereas the choice of K is less critical. In many cases, however, already the simple difference, which means set n=0 and K=1, works well as illustrated in Figure 4. The external disturbing force of repeating collisions measured by the force/torque sensor is shown in fig. 4a) and fig 4b) shows the influence to the resulting normal force measured by the tactile sensor. Using a threshold of $\Delta = 35$ gives the results presented in fig. 4c). Each time the object slips due to a heavy collision the decrease in the normal force is detected and slip is indicated by the slip indicator (slip indicator = 1).

5 Conclusions

We presented a multisensory gripper system for complex object manipulation as e.g. in the context of disassembly. The gripper jaws designed for this purpose integrate an optical array of pulsed IR sensors for detecting the presence of an object within the gripper and thus supporting also the approaching phase of the system towards an object. Further a tactile matrix sensor is integrated. It can be used for grasp force control, characterizing the quality of an established grasp, and also for slip detection during object manipulation, which is one of the most important advantages of direct tactile sensing. Therefore we also presented a fast and simple method to detect slip of an object due to external influence, which arises by contacts to other objects in the environment. The system allows the performing of manipulation tasks by a robot even in an only partially known environment so that no detailed models are necessary and thus helps increasing the autonomy of artificial systems.

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