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A Methodology for the Selection of Micro-Assembly Techniques

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Abstract: Problem statement: The study addressed the problem of selecting the appropriate micro-assembly techniques according to the micro-part features. Actually, in the micro-domain, the choice of the correct assembly technique is highly dependent on the micro-part characteristics such as shape, geometry and material. **Approach:** Since there was an incomplete and unstructured knowledge about the micro-assembly, the study proposed a Decision Support System (DSS) as solution for assisting the designer in the correct selection of the most suitable micro-assembly strategies. The first step was establishing a structured correlation between micro-assembly techniques and part features. In particular the phases grasping and releasing were adopted as test-study for their importance in the micro-assembly process. The second step was the set up of a multistage model for the selection of the grasping-releasing technique and the implementation of the model in an Expert System as a set of rules. **Results:** The DSS was tested on some common micro-parts producing a scored list of selected grasping-releasing methods. **Conclusion:** The DSS proved quite valuable in the selection and the scoring of the micro-assembly principles that suit specific applications.

Key words: Micro-assembly, grasping-releasing, capillary, micro-grippers, electrostatic, hydrophobic

INTRODUCTION

Since the nineties the number of micro-products has increased in several fields such as the biomedical, the aerospace and the automotive. Beside the Micro Electro Mechanical Systems (MEMS) manufactured by using silicon technologies, new hybrid micro-products emerged in the last years. Hybrid micro-products have a complex three-dimensional structures and are composed of several components made by different materials (Van Brussel *et al*., 2000).

The assembly cost of these hybrid micro-products can reach the 80% of their overall cost due to the predominance of manual assembly operations. Actually, it is difficult and expensive assembly them automatically because standard automatic devices are not suitable to handle sub-millimeter parts (Santochi *et al*., 2005). The main issue is the role of micro-scale adhesion forces (such as capillary, van der Waals and electrostatic forces) that overcome gravity (Paramasivam and Arumugam, 2004). Therefore, handling and in particular the grasping and releasing strategies are frequently different from the ones adopted in standard assembly.

At macro-scale, assembly and handling techniques have been widely studied. Design For Assembly (DFA) rules and systems (Redford and Chal, 1994; Boothroyd, 1994) have been developed to optimize the effectiveness and the cost of the assembly. On the contrary, in the micro-domain the Design For Micro-Assembly (DFμA) tools is at very early stages. One of the main difficulties to solve for the development of such DFμA methods is the lack of rules and former use cases that could help selecting the best couples of grasping and releasing strategies. Actually, new grasping (Tichem *et al*., 2004) and releasing approaches (Fantoni and Porta, 2008) have been proposed and developed but a systematic reorganization of them is missing. This is due also to the fact that in micro-domain the methods are strongly dependant on some part features such as dimensions, weight and material. Once a suitable grasping strategy is chosen, this grasping principle has also to be compatible with the releasing one.

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The study starts from the research of a compatibility list between component characteristics and grasping-releasing principles. Only few cases bring to a univocal solution; in general more than one choice is possible. Hence the choice becomes based on a multi-criteria space (precision of the releasing, reliability, cost, assembly time, resource consumption). Therefore it is necessary to produce an ordered list the suitable grasping-releasing couples.

An expert system was implemented, using the CLIPS language, to study as a Decision Support System (DSS). Expert system was preferred to more rigorous multi-criteria selection methods because it is able to operate in conditions of incomplete information. As a matter of fact the properties and the performances of many techniques are seldom completely assessed. Some techniques have been experimented only on a limited number of samples. In the expert system the inference engine applies a set of rules (knowledge base) to a fact list. It always supplies an answer even if some branches of the decision tree are missing.

The DSS operates in the following way: by assigning a high salience level to the exclusion rules we make them executed ahead of the others. Once eliminated the non compatible assembly strategies, the set of remaining strategies is ordered following the preference rules and the list is ranked by supplying the process engineer with a confidence value for each choice.

MATERIALS AND METHODS

Building the knowledge: The built of the knowledge base started in analogy with Boothroyd (1994) works on standard assembly. Thus the part features have been analyzed and organized in homogeneous classes: from the geometrical parameters (shape and geometry of the part envelope, block or cylinder) to its weight, to the material (liquid sensitive, magnetic, dielectric), to handling difficulties (surfaces available for grasping/releasing, space available around the object for grasping/releasing), to finally the insertion problems. In the case of parts handling difficulties have been organized into two separated groups: grasping difficulties and releasing difficulties. These part features have been associated first to the grasping strategies, then with the releasing ones. Eventually a matrix is built to correlate the parts features with both the grasping and releasing strategies. By this matrix it is possible to build the suitable couples grasping-releasing on the basis of the micro-parts features.

Table 1: Some of the considered part characteristics

Part properties	
Mechanical fragility	Surface sensitiveness
(Hereinafter each issue is in italic.)	
Porosity	Charge sensitiveness
Magnetic sensitiveness	Liquid sensitiveness
…	…
Part material properties	
Dielectric	Conductive
Magnetic	Diamagnetic
…	…

Grasping difficulties: During the last decades numerous micro-grippers based on different physical principles have been successfully developed and tested. A wide review can be found in (Tichem *et al*., 2004; Fantoni and Porta, 2008). Micro-grippers varies from standard friction and jaw grippers to magnetic, suction or Bernoulli’s ones to finally laser traps or sound pressure grasping systems. Some of them exploit capillary forces, electrostatic fields; van der Waals’ adhesion and even few ice grippers have been successfully used.

Nearly all grippers (from mechanical, to electrostatic, to capillary) can grasp a micro-part. Unfortunately the part or some of its characteristics can be damaged irremediably by the interaction (contact is not necessary) with the gripper. The wide development of micro-grippers actually hides problems as severe sticking and part damaging.

Thus the parts characteristics that can alter a proper handling by a gripper have been investigated and some of them are shown in Table 1.

Some incompatibility between part characteristics and grasping medium are due to the physical principle. Porous parts cannot be grasped using vacuum grippers, dielectric or diamagnetic or magnetic sensitive parts are not attracted by magnetic fields. More complicated is the reason why some difficulties arise when dielectric parts are manipulated by an electrostatic tool. Actually part characteristics and physical principle meets pretty well, but even a small friction between the dielectric parts and the work plane can triboelectrificate the parts making grasping impossible. Part fragility prevents the use of a tweezers, the presence of surface characteristics (optical, tribological) cancels both capillary-because they can stain the surface-and jaw grippers-because they can scratch it-and charge sensitiveness is an obstacle for an electrostatic gripper.

Releasing difficulties: In micro-assembly the most difficult task is the releasing of a micro-part rather than grasping it. Actually, due to the prevalence of adhesion forces over gravity, the part tends to stick to the micro-gripper (Santochi *et al*., 2005). Many releasing strategies have been proposed in literature (Fantoni and Porta, 2008). They are usually classified as active or passive. Passive releasing strategies exploit gripper features (e.g., hydrophobic coating, surface roughness) or environment conditions (e.g., dry atmosphere) to reduce of adhesive forces between gripper and micro-parts. Active releasing strategies (e.g., air flow, electro-wetting) allow the realizing by additional forces.

Depending on the micro-part features, it is possible to define if a particular releasing strategy can be safely and successfully adopted. Actually, some releasing strategies expose the handled part to the risks of breaking, damaging or contaminating. The part characteristics considered for the realizing are the ones previously mentioned for the grasping.

Grasping-releasing coupling: Once the part features have been analyzed with respect to the grasping and releasing strategies, it is possible to determine the suitable couples grasping-releasing. The related knowledge base has been done by building a matrix that associate, on the basis of the part features, the grasping and releasing principles. Actually not every releasing strategy can be adopted for each grasping principle (Fantoni and Porta, 2008). Furthermore the part has to be compatible with the possible grasping-releasing couple. For example, a micro-part grasped with a capillary gripper can be released heating up the gripper and evaporating the liquid. But in case of a heat sensitive micro-parts the couple capillary grasping-releasing by heating risks that the heat damages the part.

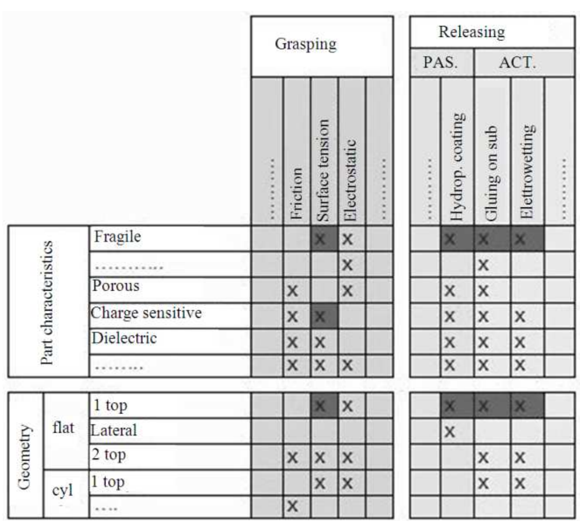

Fig. 1: Suitable grasping-releasing couples for a micro-part fragile, charge sensitive and flat with the top surface available for handling

The example shown in Fig. 1 explains how the grasping-releasing matrix is organized. In case of a part that is simultaneously fragile, charge sensitive, flat and with only the top surface available for grasping, it can be grasped with a capillary gripper and released by three different strategies: hydrophobic coating of the gripper, gluing on the substrate and by exploiting electro-wetting.

A multi-stage model of assembly techniques selection and ranking: The knowledge achieved in the former section allows us to build a model of the proper scheme for the selection of the grasping-releasing technique to be used for every given part (Bruzzone *et al*., 2009). The model is presented in Fig. 2.

The model separates the choice of the assembly in the sub-choice of grasping and releasing principles, then the two principles are put together by forming suitable couples. Using the classic approach of multi-criteria analysis, the exclusion criteria are applied as first, in order to eliminate from the list of grasping and releasing principles the ones that are not compliant with the part geometry, the part material, or where the physical property used for the principle is not applicable to that specific part. The possible couples of grasping-releasing principles are furthermore reduced by incompatibility criteria that forbid the use of grasping and releasing techniques that are in conflict with each other. At this time it is possible to apply the ranking criteria in which a score is attributed to the couple assessing its efficiency and effectiveness in exploiting the features of the part to be assembled in order to get to the design objectives. The factors to be considered in the score attribution are: geometry of the part, total dimensions, material, surface quality. Present state of the knowledge does not make it possible to give a reliable quantitative indication of how much an assembly technique suites to the problem, therefore the score must be considered as a confidence index.

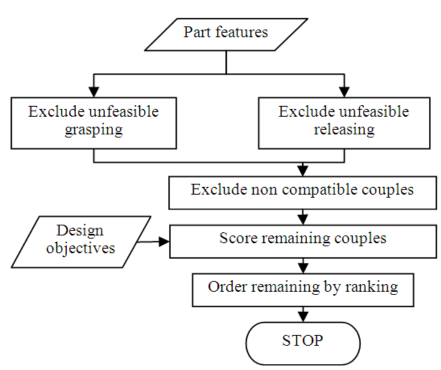

Fig. 2: The multistage model of the selection process

The final score for a couple is selected as the minimum among all the scores assigned to a couple. As the score is an index of the confidence we have when applying this assembly principle to the part case study, the final score give an approximation of the certainty with which the technique can be applied. The confidence is the probability of making the right choice, but it must be remarked that it should not be confused with the mathematical definition of probability.

RESULTS AND DISCUSSION

The decision tables (Fig. 1) are used to build the knowledge base system as expert decision rules. The rules are written in the CLIPS language. CLIPS is a forward-chaining rule based language developed as an open source project by NASA. The CLIPS shell provides the basic elements of an expert system: fact-list, knowledge-base, inference engine (Nour *et al*., 1994; Islam *et al*., 2009).

The fact list is made of the list of the part features, the list of the grasping and the releasing principles, the list of the compatible couples of grasping and releasing principles. All of them are multi-field ordered lists of facts. The facts related to the parts to be assembled obviously are created again for every application of the expert systems based on the industrial problem.

The knowledge base is made of a set of rules listed in the system. The rules in an Expert System are disposed in the list without any order. The sequence with which they will be executed is not known a priori as it is chosen by the inference engine. It is possible to force the precedence in the execution of some rules by applying a salience to the rule itself. The misuse of salience is the most common mistake in the creation of an Expert System, as it tends to constrain the decisional flow, degrading the expert system to a mere decisional tree.

In this study, only two different salience values are used: high and low priority (the assigned number has no relevance). The salience is used only to force the precedence of the application of the exclusion rules before the ordering rules are applied. It was possible not to use salience at all and have the inference engine decide the order of execution of all the rules. The result would have been the elimination of already ordered couples grasping-releasing with a general loss of efficiency and without increasing the space of the solutions. An example of rules is reported in Fig. 4 together with the translation in current English (Fig. 5). The rule is used to exclude the friction principle when grasping fragile parts or parts with optical properties.

```
(deffacts grasping_process
        (grasp Friction)
        (grasp Suction)
        (grasp VanDerWaals)
        (grasp Cryogenic)
        (grasp Magnetic)
        (grasp Electrostatic)
        (grasp Surface_tension)
        (grasp No_contact))
```

Fig. 3: A fact list reporting the known grasping principles

```
; Grasp exclusion rule 1
(defrule noncomp1
        (declare (salience ?*high-priority*))
        (property fragile|optical y)
        ?pointer <- (grasp Friction)
=>
        (retract ?pointer))
```

Fig. 4: The exclusion rule in CLIPS language

Grasp exclusion rule 1

To be executed before the ranking rules
IF
    the part is fragile
OR
    the part has optical properties
THEN
    retract Friction from the list of grasping principles

Fig. 5: The exclusion rule in natural language

Principles ranking

Handling Principle		Confidence
No contact (all)		90
Surface tension	Hydrophobic	80
Surface tension	Adhesion	80
Surface tension	Gluing	80
Surface tension	3D Handling	70

Fig. 6: The proposed processes for flat, fragile, charge sensitive parts

The DSS was tested in order to suggest the preferred micro-handling techniques to execute various assembly tasks typical of micro-mechanical components: e.g., pick and place of micro-spheres and micro-gears, peg in hole of micro-cylinders. These three families of tasks compose a benchmark that was used to set up a complete assembly micro-factory (Bruzzone *et al*., 2009). The DSS predicted a list of principles for every task that were sound and compliant with the experts proposals. As an example, the application of the DSS to flat, fragile parts (the teeth of the gear wheel are considered fragile in this dimension scale), charge sensitive produced the results reported in Fig. 6, in order of confidence.

CONCLUSION

The proposed DSS is presently an effective tool for choosing among several alternatives assembly principles. The DSS gives a ranking of alternatives based on material properties and on the desired assembly accuracy. As the same principle can be implemented in many different ways in a technological process a further extension will be the introduction of detailed rules for choosing a specific technological process.

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