A CRITICAL REVIEW OF RELEASING STRATEGIES IN MICROPARTS HANDLING

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Abstract In the last ten years, various grasping principles and releasing techniques suitable for microassembly have been hypothesised and successfully tested. Since in microdomain adhesion forces overcome the gravity one, new grasping principles have been exploited to grasp microparts. Unfortunately, in microassembly the most critical phase is not to grasp a micropart, but to release it. Therefore, the development of releasing strategies plays a fundamental role in the entire assembly cycle. This paper proposes a scheme for classifying many releasing strategies developed in the microassembly field, provides a map of interesting grasping-releasing couples and analyses in detail one of the most reliable grasping principles (i.e. capillary gripper) and the related possible releasing strategies. Finally, a procedure for the selection of grasping and releasing strategies on the basis of the components to be handled and on the boundary conditions is provided.

Key words releasing, design for microassembly, grasping

1 Introduction

In the microassembly process, grippers are very important because they have to pick up microparts and release them with the correct orientation in the right place with high accuracy. Furthermore, they have to not damage or contaminate the microparts they handle. Many strategies have been developed for grasping microparts and the gripper configuration depends in general on the features of the object to be grasped and on the dominant forces at microscale [1]. Some microgrippers have been directly downscaled from the macro world while others, thanks to the very small dimensions and mass of handled microparts, take advantage of surface forces or other physical effects. A few authors have developed microgrippers changing systems [2] to handle many different microcomponents.

With the exception of few contactless grippers (e.g.: Bernoulli's, laser and sonodrote grippers), the main problem of the contact ones (exploiting friction, suction, jaw, surface forces etc.) concerns the releasing task. The gravity force, generally used in traditional assembly to release components, is often less relevant than adhesion forces in microdomain. Hence, components tend to remain stuck to the gripper, causing the need for the development of innovative releasing strategies.

Even if the releasing phase has been deeply discussed in [3, 4], novel strategies and approaches have been developed in the last few years. Therefore an up-to-date survey seems to be necessary. The methodology chosen in this paper for the study and the analysis of the releasing strategies in microassembly consists of the following steps:

- it starts from the collection of literature concerning the releasing phase;
- data are organised to highlight problems, advantages and opportunities of each releasing method;
- grasping strategies are coupled with the considered releasing methods;
- finally, each grasping principle has to be analysed to investigate possible releasing solutions: in this paper the capillary principle is considered as an example.

2 Grasping and Releasing Strategies in Microdomain

The main sources for the analysis of the releasing principles and strategies were papers, websites and technical documentations. This analysis allows the authors to cluster homogeneous papers and to organise them expanding the taxonomy from general principles to detail solutions.

The ontology proposed here splits the releasing strategies into two separate groups: *passive releasing strategies* (Table 1), where suitable gripper features or environment conditions make possible the reduction of adhesive forces between gripper and microparts; and *active releasing strategies* (Table 2), where parts can be released by means of additional actions. *Passive releasing strategies* exploit **microgrippers features** (in terms of shape, surface coatings and material) or **environment conditions** to reduce the force acting at the microscale, such as electrostatic, adhesion, van der Waals ones. On the contrary, the *active releasing strategies* make use of additional actions to allow the grasped object to be detached from the gripper. These additional actions can be (i) **forces** able to overcome the adhesive ones between gripper and object or (ii) **means** to reduce the **contact area**. With regard to additional forces, they can be supplied by external equipment or by suitable substrate (or substrate features) where the objects have to be released.

It is important to highlight that often releasing strategies make use of more than a single approach at the same time: in this case the authors tried to recognise the most significant releasing method. Furthermore obvious adjustments, such as for example a clean environment (dust is recognized to be a factor that modifies adhesion forces and friction [3]), are considered basic requirements for handling and do not appear in Table 1 and 2.

Tables 1 and 2 are organised as follows: each *Releasing Principle* is briefly described and a *Scheme* is provided. The *Releasing Principle* is defined as the physical principle which (i), decreasing the adhesive forces, makes gravity and/or other forces able to detach the part from the gripper or (ii), overcoming the adhesive forces, causes the releasing of the micropart. Table 1 (passive releasing strategies), differs from Table 2 (active releasing strategies) because it has not the columns *Problems* and *Released components.* Actually, while Table 1 contains general design rules applicable in cases of direct contact between the gripper and the micropart, conversely Table 2 also describes the *Problems* derived by the introduction of additional forces and provides a list of the *Released components*.

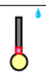
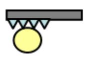
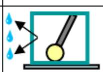
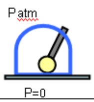
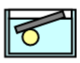
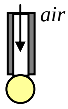
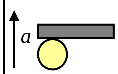
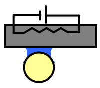
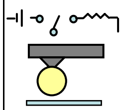
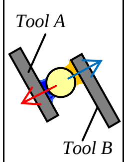
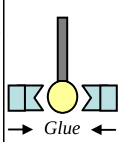
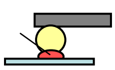
Type	*Principle*	*Scheme*	*Description*	*Force*↓
Gripper	Conductive material/coatings -*Grounded gripper*		Conductive materials or coatings (which do not form insulating oxides) reduce static charges. Grounded grippers prevent the charge storage [3, 5]	electrostatic
	Low difference of EV potential		Gripper and object made of materials with a small potential difference reduce “contact interaction” forces [5]	electrostatic
	Hydrophobic coating		Hydrophobic coating reduces surface tension effects: it prevents the adsorption of moisture [6]	surface tension
	Low Hamaker constant Coating		Low Hamaker constant coating reduces van der Waals forces [3]	van der Waals
	Hard materials		Contact pressure causes deformations, increasing the contact area between gripper and object: grippers made of hard material have to be preferred [5]	van der Waals; electrostatic
	Rough surface -*Micro pyramids*		The gripper roughness reduces the contact area and sharp edges induce the self discharge effect [5, 6]	van der Waals; electrostatic
	“Spherical” fingers		Spherical fingers reduce the contact area in comparison with planar ones [5]	van der Waals; surface tension
Environment	Dry atmosphere/ Heating the environment		A dry atmosphere reduces surface tension effects (but increases the risk of triboelectrification and the generation of electrostatic force) [3, 5]	surface tension
	Vacuum		If no moisture affects the contact, there is no liquid bridge and so surface tension is reduced [5] (but risk of triboelectrification)	surface tension
	No O_2 in the environment		If there is no oxygen, native oxide can not arise on the surface of gripper/handled objects [5]	electrostatic
	In fluid releasing		Assembly in fluid eliminates surface tension effects and reduces electrostatic force [5, 7]	electrostatic; surface tension
	Ionized air		Ionized air can neutralize free charges on the surfaces and so it reduces electrostatic force [8]	electrostatic

Table 1. Passive releasing strategies

Type	*Principle*	*Scheme*	*Description*	*Problems*	*Released components*
forces	Air pressure *1.Direct* *2.Indirect (Adsorption force)*		1. An air pressure flow [9, 10] overcomes adhesion forces; 2. By heating a suitable end effector the object is released thanks to the adsorption force [8]	Possible lack of precision in the releasing place	1. 50-300µm parts [9]; square silicon chips (4.2*4.2*0.5mm^3) of 20.5mg; [10]; 2. Max. adsorption force 0.22µN [8]
	Acceleration Or vibration		An acceleration or a vibration given to the gripper support allows the object to be detached thanks to inertial forces [11, 12, 13]	Possible lack of precision in the releasing place [13]	40µm pollen microspheres [12]; 400µm spherical and 900µm half spherical lenses [13]
	Micro heater *1.Evaporating moisture/liquid* *2.Melting ice*		1. A micro heater reduces the moisture-liquid (so surface tension-capillary forces) [3]; 2. Melting of ice (ice gripper) [14, 15]	Temperature sensitive parts can be damaged by heat	SMD plastic elements, small copper coils for telecommunication [14]
	Electrostatic force control *1.Shorting the gripper* *2.Voltage tuning* *3.Inverting polarity*		Parts are released by the electrostatic force control: 1. Shorting down the gripper electrodes [3]; 2. Tuning the electrostatic force between gripper and substrate [16]; 3. Inverting the polarity [17, 18]	Problem in releasing conductive components [18]	2. Metallic spheres of d=30µm [16]; 3. Spheres of d=100-800µm and cubic valve (l=l80µm) [17]; Spheres, cylinders of 300-1000µm [18]
	Different adhesion force *1.Adhesion on substrate* *2.Different adhesion tools* *3.Different volume of liquid*		Objects pass from a tool A to a tool B exploiting the difference in adhesion force between the tools and the object. The tool B can be: 1. A substrate [17]; 2. A gripper [12]; 3. The force difference can be given by different volume of the same liquid [19]	The object has to be detached from the tool B (if the releasing place on tool B is not the final place)	1. Glass spheres with d=100-800µm and cubic valve flap with edge l80µm [17]; 2. 40µm pollen microspheres [12]
	Engagement by the substrate/ tool *1.Snap* *2.Against edge* *3.Scraping* *4.Rolling* *5.Needle*		The object is released by its mechanical engagement on the substrate [10] or another tool. This strategy includes: 1. The use of snaps [20]; 2. Part against an edge [9, 21, 22]; 3. Scraping [12]; 4. Rolling [12]; 5. Use of needle [10]	Often additional features on the substrate are required	2. Metallic/non metallic parts of 50-300µm [9]; 3.-4. 40µm pollen microspheres [12]; 5. Square silicon chips (4.2*4.2*0.5mm^3) of 20.5mg; [10]
	Gluing on substrate		Parts are released by gluing them on the deposal place [10]	Not suitable for moving parts	Square silicon chips (4.2*4.2*0.5mm^3) of 20.5mg; [10]

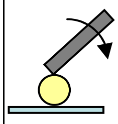
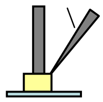
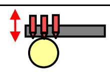
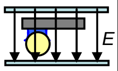
reduction of the contact area	3D handling of the gripper *1.Variation the curvature* *2.Tilting* *3.Parallel motion*	 *Add. tool*	A decreasing of the contact area through: 1. Varying the gripper curvature from a flat shape to a curved one [23]; 2. Tilting the gripper [24]; 3. Parallel motion of the gripper respect to the substrate [25]	Complex 3D handling of the gripper. Many DOF required.	1. Minimum object weight 98mg [23]; 2. Metallic spheres of d=20-30µm [24]; 3. 40µm pollen microspheres [12]
	Additional tool		An additional tool (with little contact area with the object) allows the object to be first detached from the gripper [24], then released on the substrate by removing the tool	Many devices in a small space	Metallic spheres with diameter of 20-30µm [24]
	Roughness change		The roughness change reduces adhesion forces allowing the part to be released [3]	Difficulties in realization	
	Electrowetting		The modification of the liquid drop by an electrostatic field reduces the contact area [11]	Difficulties in meniscus control	

Table 2. Active releasing strategies

The classification schemes proposed in Tables 1 and 2 have to be considered as necessary steps for the development of rules for the selection of the most suitable couples of grasping-releasing principle. Actually, in order to make grippers able to pick and place microparts in a reliable way, often a grasping approach has to be coupled, from the design phase, with one or more releasing strategies. Table 3 updates the works presented in [26, 27] and has been created to map the grasping principles and the possible releasing strategies adopted and/or suggested in literature. The grasping methods are adapted from the classification of grasping principles carried out by [1], while releasing methods come from the classification reported in Tables 1 and 2. In comparison with [1], the item "Surfaces forces (general)" has been introduced in grasping methods to include authors that generally refer to adhesive forces as grasping forces [24].

				GRASPING PRINCIPLES						
				Friction	Cryogenic	van der Waals	Electrostatic	Capillary force / surface tension	Surface forces (general)	Suction
RELEASING PRINCIPLES	Passive Releasing	*Gripper*	Conductive material/coatings	[5]		[3]	[3]		[3]	
			Low difference of EV	[5]						
			Hydrophobic coating					[11, 28]	[4]	
			Hard materials	[5]						
			Rough surface	[5] [6]		[3]			[3]	
			“Spherical” fingers	[5]						
		Environment	Dry atmosphere	[5]					[3]	
			Vacuum						[3]	
			In fluid releasing						[7]	
			Ionized air				[3]			
	Active Releasing	*Forces*	Air pressure					[10]		[9]
			Acceleration or vibration				[13, 18]	[11, 12]	[3]	
			Micro heater		[14, 15]				[3]	[8]
			Electrostatic force control				[17, 18, 29]		[3]	
			Different adhesion force				[17]	[12, 19]		
			Engagement by the substrate				[22]	[10, 12]		[9]
			Gluing on substrate					[10]		[30]
			3D handling of the gripper			[25, 31]	[24]	[11, 12]		
		Contact area	Additional tool				[24]	[11]		
			Roughness contact area	[3]						
			Electrowetting					[11]		

Table 3. Releasing strategies available for grasping strategies

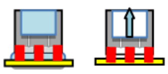
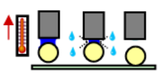
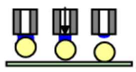
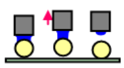
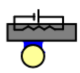
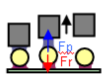
3 Releasing Strategies for Capillary Gripper

Each grasping principle and all the possible releasing methods in Table 3 can be analysed further. Hereinafter the case of capillary gripper has been used as an example. As demonstrated by the numerous papers in literature [19, 21, 23], the capillary gripper is one of the most reliable. The advantages of capillary grippers are [21] the ability to grasp:

- small components (the available capillary force is few mN);
- components with only one upper free surface;
- components with a small available grasping area;
- any kind of component in terms of material and shape;
- fragile components because the meniscus acts as a “bumper”.

Moreover there is a favourable downscaling law (the force is proportional to the linear dimension). Finally, the capillary gripper is compliant and exerts a self centering effect due to surface tension.

Most of the releasing strategies in Tables 1 and 2 can be used for releasing objects grasped by capillary grippers. Unfortunately, the releasing phase is difficult even if numerous systems have been tested. Table 4 focuses on releasing approaches developed in literature for capillary grippers.

			Principle	*Scheme*	*Problems/Difficulties*	*Advantages*	*Released compo-*
RELEASING PRINCIPLES	**Passive release**	*Gripper*	Hydrophobic coating		-Manufacturing difficulties -Resistance of coating to few cycles	-Flexibility -Manufacturing by silicon technologies	Prevalently flat parts
		Envir.	Dry Atmosphere (heating the environment)		-Energy consumption -Long cycle time -Scarce reliability	-Easy to be realised	Probably all shapes
	Active releasing	*Forces*	Air pressure		-Precise control of the volume and pressure of air	-Precise if done in contact with the substrate	All parts
			Acceleration or vibration		-Lack of precision in releasing	-Easy to be realised -Reliable releasing	Parts with not too low mass
			Micro heater		-Reach exactly the drop -Risk to damage temperature sensitive parts	-Various types of heating source -Local action	-All parts except temperature sensitive ones
			Different adhesion force		-The precise control of the dispensed volume of liquid is difficult	-Self centering of the object on the releasing drop	All parts

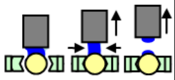
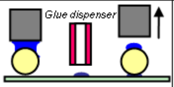
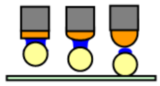
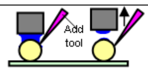
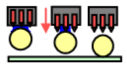
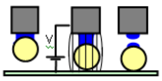
			Engagement by the substrate/tool		-Often not precise -Releasing from other tool -Structured substrate -Damages on the part	-Reliable releasing	It can depend on substrate features
			Gluing on substrate		-Releasing precision depending on the glue -Glue volume control -Glue curing	-Self centering on the glue drop	All parts
			3D handling of the gripper		-Difficulties in the surface curvature control -Difficult to reach small radii of curvature	-Flexibility -Many actuation strategies are available	Prevalently flat parts
		Contact area	Additional tool		-Difficult to reach the part without wetting the tool -Damages on the part	-Precision	Probably all; better if flat parts
			Roughness change (*increase gap)*		-Manufacturing difficulties -Need for hydrophobic needles	-Flexibility	Probably all; better if flat parts
			Electrowetting		-Difficulties in meniscus curvature control -Charges induced both in liquid and component	-Direct control of the liquid meniscus (force)	Prevalently spherical parts

Table 4. Releasing strategies related to capillary grasping

4 Selection of Suitable Grasping-Releasing Strategy

As reported in [1], the selection of the suitable microgrip principle depends both on *part characteristics* in terms of physical and functional features (such as material, shape, mass, function, etc.) and on the boundary conditions (i.e. environment and assembly tasks). Once the grip principle has been chosen, it is necessary to verify which are the releasing strategies suitable to be coupled with the selected grasping approach (Table 3). If no releasing strategy shown in Table 1 and 2 makes possible the releasing of the components, a different microgrip principle has to be selected. Hence, only a correct selection of both the grasping and the releasing strategy allows a reliable design of the gripper. Actually, for each grasping method various releasing approaches can be used but, as shown in Table 4 for capillary grippers, every releasing strategy presents some advantages and drawbacks and is suitable to release components with particular features.

The procedure, proposed for the selection of the grasping-releasing strategy, is shown in Figure 1.

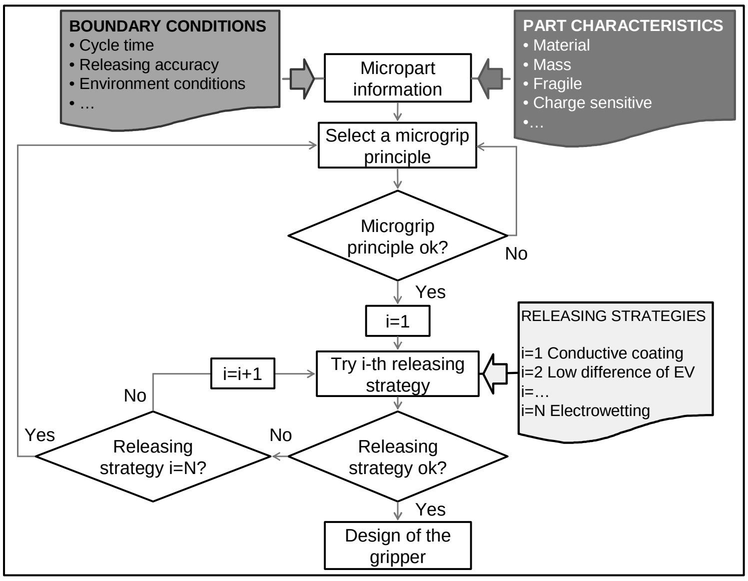


Figure 1. Conceptual procedure for the grasping-releasing selection

With regard to **part characteristics**, *geometrical parameters* are one of the first drivers in the selection. For example (see Table 4), a flat component could be grasped and released with capillary grippers owning hydrophilic and hydrophobic coating but probably the same gripper is not able to handle spheres and cylinders. Moreover, it is necessary to know the *component properties and functions,* i.e. if components are fragile, porous, dielectric, conductive, magnetic, diamagnetic, charge and water sensitive, etc. and/or if their surface is polished or must have optical characteristics. Actually, fragile parts can be damaged by mechanical grippers but also by a high stress releasing such as an engagement on the substrate or the use of an additional tool. For instance, charge sensitive SMD are altered by electrostatic grippers or electrowetting releasing. Optical lenses can be stained by the remaining traces left by liquid grippers. Similar damages can occur when these parts are released with glue or mechanical tool such as needles.

With regard to the **boundary conditions**, information about the *initial status* of the microparts is also necessary to choose the best grasping tool. Therefore different choices can be done if the parts are randomly positioned or correctly fed, if they are separated, regularly spaced (ordered) or they present difficulties in feeding (e.g. they stick, nest, tangle, or they are slippery, flexible, squiggle etc.). For example, an adhesive or an electrostatic gripper is not able to pick only a sphere from a group of some spheres in contact. Conversely if the parts are sufficiently spaced both principles can be successfully exploited. Also the requirements of the *final positioning* (2D, 3D, fine, coarse, etc.) determine the choice of the gripper or conversely prevent the use of some grasping principles. For example, a compliant adhesive gripper cannot be used for a forced peg-in-hole operation, while it could be particularly suitable for pick-and-place operation of delicate micro parts. Finally, the *environment* plays a fundamental role because it can allow or prevent the use of some grasping principles: even in a clean environment the small amount of dust can dramatically reduce the performance of a gripper (such as an electrostatic one) both in the grasping and in the releasing phase.

5 Conclusion and Future Development

A critical survey of the releasing strategies in microassembly has been performed. These strategies are organised in a novel classification scheme to allow a structured selection of the suitable methods for releasing a grasped microcomponent. Then, a matching of the possible releasing approaches related to each grasping principle has been developed and it should help the designer with a simple decision map. Furthermore, a deeper analysis of a particular microgripper (i.e. the capillary one) has been performed: the releasing strategies, allowed in this case, are compared in terms of advantages, drawbacks and handled components. In order to help the designer in the right choice of both grasping and releasing principle a step-by-step procedure has been finally proposed.

Future works concern the development of Design for Microassembly rules by extending this work to other grasping principles and assembly operations as for example microfeeding, microsorting, microinserting, microforcing and microgluing.

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