Method for supporting the selection of robot grippers

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Abstract

The aim of the paper is to lay the basis for the development of an expert system for the selection of robot grippers. The work started with a review of the literature concerning (i) grasping principles, (ii) releasing strategies and (iii) main problems concerning the automatic assembly and, more in general, the handling. Actually, the choice of a gripper cannot be done only relying on the object characteristics: indeed, many other parameters as feeding conditions, handling characteristics, positioning and releasing conditions deeply affect the right choice.

First the paper defines a set of parameters that will be the input of the method. A precious, but not exhaustive, source of information is the past work on Design For Assembly (DFA) where parameters, rules and warnings were defined and can be reused for the new purpose.

Then a set of rules have been created to guide the user in the choice of the most suitable grasping principle. The analysis of the literature on grippers allowed the research group to develop a wide DB of examples both coming from industry and academia.

Once a suitable grasping strategy is chosen, this grasping principle has to prove of being compatible with the releasing phase. Therefore a compatibility matrix between component characteristics and grasping-releasing principles has been proposed and developed. The work ends with a series of tests among which a case study describing a selection of a suitable gripper for food industry is shown.

1. Introduction

Because of the wide variety of objects manipulated in industrial processes, many different grippers, based on different principles, have been developed. Gripper choice or gripper design is often considered the last problem to be solved when a process is automatized. In this way the choice is often a compromise solution, or only the most common grippers are adopted to satisfy the task. Given the task to be accomplished and the growing variety of grippers and strategies, the selection of the most appropriate gripper is not only difficult because of the wide variety of existing ones but because the existence of incompatibilities with some requirements characterizing of the operation. Thus a certain level of rejects due to bad handling may be accepted even if they are caused by the erroneous choice of the gripper.

For a company the adoption of a new kind of gripper could improve the duty cycle of the operation, the reliability of the whole system and reduce the cost. The present paper investigates a methodology for supporting the selection of the grippers able to accomplish a determined task.

The paper is organized as follows: Section 2 presents the state of the art with a focus on DFA methods. Section 3 presents the methodology, while case studies are reported in Section 4. Section 5 presents some conclusions and possible future developments of the system.

2. State of the art

Since human beings are very familiar with object prehension, the process of automatizing the grasping of an object is often underestimated. In fact when objects have to be grasped in an automatic way, many problems arise: many depend on the object physical properties (e.g. porosity and deformability), but also the conditions in which the object is fed and the characteristics of handling, positioning and...
releasing increase the complexity of the gripper choice. Parts correctly fed require a less versatile gripper, while in bin picking situation the gripper has to properly grasp pieces with different positions, orientations, part tangling, etc. Similarly, high accelerations, reorientations, high precision releasing etc. during the handling phase, increase the constraints in the gripper design or choice.

Boothroyd & Dewarst [1], Lucas [2] and Andreasen’s [3] DFA (Design For Assembly) methods are the three main methods for DFA. The authors observed many workers during assembly to compute assembly times, handling difficulties, physical and geometrical characteristics of the parts, insertion difficulties and other aspects of the assembly phases. Moreover they interviewed many experts in order to understand how to overcome specific assembly problems, and finally arranged all the relevant information in the DFA framework.

The central problem of any new DF-X is the definition of the key design parameters influencing the quality of X. Such parameters should supply indications about a good design and must be easy to be measured in the first conceptual phase of the product development. Parameters must also be objective, accurate and easy to be understood [4].

Many of the solutions adopted in DFA techniques have been useful during the development of the present work, in particular issues related to Handling difficulties, Feeding problems and Placing represented the baseline of the analysis. Another valuable contribution comes from the DFH (Design For Handling) techniques, which aim to redesign the object in order to be easily handled from automatic systems [5].

Although the grasping phase is already taken into account in the DFA, a specific tool to evaluate alternatives grippers does not exist nowadays. Some preliminary efforts have been done by FESTO, that developed a selection system for its mechanical grippers[6].

A general tool that helps the designer in the selection of the proper gripper in case of objects with different dimensions, characteristics, and handling constraints does not exist at present. Its development implies many issues, such as the identification of key parameters, the organization of the grippers in a database, the analysis of correlations among parameters and the collection of design rules.

3. Method

The methodology works interacting with the user through a series of questions concerning the object, the handling operations and other possible requirements. It also aims to help the user into the selection of the suitable grasping principles relying on a predetermined set of parameters and rules.

Parameters, which describe the problem, have been investigated, defined and finally selected with the purpose to consider all the phases in which the gripper is involved: feeding, grasping, handling and releasing. Also the robot which manipulates the gripper influences gripper capabilities and therefore its proper choice. However, this introduces another degree of complexity which cannot be evaluated at this stage of the analysis.

Rules, described in Section 3.3, are activated upon the occurrence of a determined condition triggered by the value assigned to one or more parameters.

3.1 System logic

A deep analysis of the DFA techniques [1] helped to define part of the structure, the logic and the parameters connected to warnings and advice.

In Fig. 1 the decisional steps of the methodology are briefly synthesized. Steps involving releasing strategies and compatibility check are mainly for micro-parts. In fact, in assembly processes dealing with micro-components (components with a size in the range between 10 μm and 10 mm) the adhesion forces (electrostatic, Van der Waals, surface tension and viscous forces) are usually neglected. Thus gravity and inertial forces [7] become less relevant than at the macroscale. In fact the releasing phase of a micro object could become really challenging due to adhesion between the object and the tool [8] thus requiring specific releasing strategies.

Fantoni and Porta [9] collected the main releasing strategies at microscale and defined the compatibility between releasing strategies and grasping principles.

The parameterized description of the problem (filled by the user) and the set of rules (gathered by the literature analysis) constitutes the input, as shown in Fig. 1. The input is responsible for the exclusion of unfeasible grasping principles and releasing strategies which are automatically selected from pre-defined lists. Then the compatibility between grasping principles and releasing strategies is double checked in order to avoid improper selection of grasping-releasing couples.

The output is composed of the list of appropriate grasping principles together with possible warnings, advice and environmental requirements. Furthermore, for each selected grasping principle, a list of specific minimum requirements is given in order to enable automatic searches into the gripper database.

![Fig. 1. Scheme of the expert system.](image-url)
3.2 Parameters

Parameters can be assigned to two different macro categories: the first one describes the object properties, while the second describes the operation.

The first macro category includes physical and geometrical properties of the workpiece. The second one is divided into three categories:

- placing (e.g. high precision alignment);
- feeding (e.g. oriented/unoriented state of the fed object);
- handling (e.g. lifting, moving, reorienting).

Parameters can be Boolean or multi-valued. Boolean parameters, e.g. sensitivity to liquid, can assume two opposite values: True or False. Conversely, multi-valued parameters, e.g. stiffness, are defined to evaluate different levels of the considered parameter (at least three different levels: Low, Medium, High).

A correlation analysis between parameters allowed to verify the coherence, to establish a proper order and to avoid possible contradictions.

Table 1. List of the parameters related with the corresponding categories.

| Object       | Operation   | Physical | Geometric | Feeding | Handling | Placing | Reference |
|--------------|-------------|----------|-----------|---------|----------|---------|-----------|
| Weight       |             | ✓        |           |         |          |         |           |
| Size         |             | ✓        |           |         |          |         |           |
| Density      |             | ✓        |           |         |          |         |           |
| Porosity     |             | ✓        |           |         |          |         |           |
| Slippery     |             | ✓        |           |         |          |         |           |
| Stickiness   |             | ✓        |           |         |          |         |           |
| Hydrophobic  |             | ✓        |           |         |          |         | [10]      |
| Hygienic req.|             | ✓        |           |         |          |         | [11][12]  |
| Sensitivity  |             | ✓        |           |         |          |         |           |
| Conductivity |             | ✓        |           |         |          |         | [11][13][14] |
| Ferromagnetic|             | ✓        |           |         |          |         |           |
| Wet          |             | ✓        |           |         |          |         |           |
| Stiffness    |             | ✓ ✓      |           |         |          |         | [15][16][17] |
| Shape can change |         | ✓ ✓      |           |         |          |         |           |
| Roughness    |             | ✓ ✓      |           |         |          |         | [14][18]  |
| Toughness    |             | ✓ ✓      |           |         |          |         |           |
| Shape        |             | ✓ ✓      |           |         |          |         |           |
| Symmetry     |             | ✓ ✓      |           |         |          |         | [1]       |
| Presence of holes |         | ✓ ✓      |           |         |          |         |           |
| Hole for grasping |       | ✓ ✓      |           |         |          |         |           |
| Planar surface |           | ✓ ✓      |           |         |          |         | [5]       |
| Regular curved s. |       | ✓ ✓      |           |         |          |         | [5]       |
| Stacked      |             | ✓ ✓      |           |         |          |         | [1][16]   |
| Tangled      |             | ✓ ✓      |           |         |          |         | [1]       |
| Oriented state |           | ✓ ✓      |           |         |          |         | [19]      |
| Known position |           | ✓ ✓      |           |         |          |         | [19]      |
| Orienting    |             | ✓ ✓      |           |         |          |         | [1]       |
| Acceleration |             | ✓ ✓      |           |         |          |         | [19][20]  |
| Aligning     |             | ✓ ✓      |           |         |          |         | [1]       |
| Inserting    |             | ✓ ✓      |           |         |          |         | [1]       |

However, some parameters cannot be evaluated in the input phase, such as the grasping direction and the need of a monitoring system, since they are strictly linked to the specific grasping principle adopted and therefore recursive.

In Table 1 parameters are related to physical and geometrical properties of the object, or with the operation phase where they are mostly involved. Even if parameters have been studied in order to be decoupled and to belong to only one category. However in some cases this has not been possible (e.g. stiffness is related both with physical and geometrical properties).

Many of the parameters are self-explaining, while others require the definition of their application field: Hygienic requirements concern the types of products which have to meet specific standards about contamination levels allowed; Sensitivity represents how an object can be influenced by different elements, such as liquids, dust, heat etc.; Predetermined position is needed to establish whether the system knows the exact object position; Regular curved surface has been introduced in order to define if the surface, even if not planar, is suitable for grasping; Toughness evaluates both traction and compression resistance.

Furthermore, it is necessary to distinguish between Oriented state, which represents whenever the workpiece is fed already oriented or not, and Orienting, which implies that the gripper has to change the workpiece orientation into a different state than the initial one.

3.3 Rules

At this step the methodology needs for a specific set of rules. Rules work according to the problem described through the set of parameters and can be organized into three different categories:

- Exclusion rules: they exclude one or more grasping principles or releasing strategies;
- Warnings: they warn the user about how the operation should be done or what should be avoided. For instance recommend to avoid high accelerations, or the warn about the need of a monitoring sensor when dealing with very fragile objects;
- Advice: they advise the user about the opportunity of redesigning the workpiece in order to make it more suitable for automated handling.

At this stage the rule list counts around 200 items: mostly exclusion rules.

3.4 Gripper Database

Two hundred and fifty papers, coming from the analysis described in [21] have been collected in a database. Each paper has been matched with the parameters described in Table 1. Each cell contains the value of the parameter, if the experiment shown in the paper presented such an information, otherwise the corresponding cell was left empty.

Generally papers describe a specific scenario where a novel gripper is tested with a small set of possible objects. Therefore it is not uncommon that many parameters cannot be easily “deductible”, then the table results to be quite sparse. This, is partially mitigated by the high number of papers.
contained in the database. The lack of standardized data in technical documentation represents the counterpart from the industrial side. This limit becomes more relevant when dealing with the most recent and innovative grippers or grasping principles, making a detailed, complete and coherent population of the database not possible.

Table 2 is a sample of how the gripper database is populated.

4. Case studies

The reliability of the proposed methodology has been validated through two case studies: the first one is a standard pick and place operation of a simple mechanical part, while the second one concerns a more complex scenario: the object is a fish fillet and the operation misses an appropriate feeding process.

4.1 Exemplary case

The object to be manipulated is a steel cube of edge length of 51mm. On the faces there are very small drilled holes, whose area covers more than 50% of the total surface available. The weight of the object is 330g.

The selected grippers for the required operations are the ones belonging to the following categories:
- friction two fingers;
- friction jaw;
- magnetic.

Other grippers have been excluded mainly because of the shape and the density of the object. Others, such as the suction ones, have been excluded because of the presence of holes. Since the diameter of the holes is 2 mm, thus expansion grippers cannot be used for grasping.

It is interesting to note how three fingers grippers have been excluded, even if belonging to the friction ones, since the grasp is not stable because of the object shape.

4.2 Validation - Food

For the validation of the methodology a fish fillet has been chosen since it embodies a series of characteristics (such as fragility, deformability, sensitivity to contamination, wettability) that makes it not suitable for automatic grasping.

The fish fillet size is 50x65x25 mm and weighs approximately 80g.

The operation consists in a pick and place where the object is fed through a conveyor, in a random position and orientation, and subsequently it is placed on another conveyor without any specific orientation.

The selected grippers for the required operations are the ones belonging to the categories in Fig. 2. For the friction gripper, a grasping force of 2.35N has been defined as the minimum value to efficiently hold the object in case of small accelerations during the handling phase. For this type of gripper, some design advice are given, as for example the minimum finger stroke and minimum finger length.

Furthermore (i) a vision system to recognize object orientation and position is needed, and (ii) every gripper must also be designed to meet the hygienic standards required. Electrostatic and Van der Waals grippers have been excluded due to the presence of water which significantly reduces their grasping force [22]. Similarly, capillary and acoustic grippers have been excluded due to the low grasping force related to object shape and density.

Table 2. Samples of records from the gripper database.
4.3 Validation - Liquid glue
Small bags filled with liquid (glue) are transported through a conveyor belt and at the end must be packed in a card box. At the present the packaging operation is performed manually.

The polyethylene bags are sensitive to scratches, are slippery, deformable, sensitive to heat. The bag size is 300x200x25 mm and its weight is approximately 450g. The automatic operation consists in picking the object and placing it in the box.

Mechanical friction grippers have been excluded owing to the deformability of the sack and to the slippery condition of its surface. The presence of water and the industrial environment prevent the use of electrostatic and van der Waals grippers. Bernoulli or Coanda grippers cannot be used owing to the deformability and weight of the object. Also in this case capillary and acoustic grippers have been excluded due to the low grasping forces they can exert.

Vacuum grippers could be adopted even thought their reliability reduces when the object deforms. Form grippers as for example the fork grippers can be adopted. The solution is well known and many industrial end-effectors have forks to handle sacks, bags, etc..

However another gripper seems to have the ability to grasp the flexible bag: the Switl®. It is a friction gripper similar to a shovel. It behaves as a shovel and as a conveyor belt simultaneously. It is formed by an advancing-retracting spatula covered by a textile belt. The Switl® [23] approaches the object, then the spatula advances and the belt is spread below the object without (almost) any friction. The gripper is moved with the object on top, located in the final position and the process is performed backwards: the spatula is retracted, the belt is winded on again and the object released.

The Switl® grasps and handles very soft and deformable objects (even in sol or gel state) without modifying their shape.

4.4 Validation - Lightweight wood inlay
For producing inlaying works, wood parts are obtained from foils through laser cutting. Each single part has to be grasped and located in the right place to form the final inlay.

The main problems are: the parts are rigid but tangle with the surrounding elements (parts or debris), the only access is from the top and the surface is partly porous. Mechanical fingers and form grippers cannot be used owing to the presence of lateral parts. Electrostatic and electromagnetic principles does not work with wood, vacuum does not match with the porosity characteristic. Needle gripper can be used but particular attention have to be paid to scratches and imprints. Thermoplastic glues (Liquid-Solid transition grippers) can be exploited as well as no contact handling systems as for example Bernoulli grippers [15] or ultrasound grippers. Due to the porosity of the part vacuum is not the best choice from an economic point of view but, neglecting the waste of energy it can be successfully used as it has done in case of green tapes in [24].

4.5 Validation - Hollow bricks
The handling of many hollow bricks at time is quite a critical task owing to problems related to the presence of holes, fragile materials, environmental conditions as dirty and irregular surfaces.

This set of characteristics is almost fully mapped in the DB by two similar items: gripper for grasping bricks (without holes) and gripper for roof tiles. The first one is a vacuum gripper [25] the second one is a modified version of [26] by BIBA [27]. However the first one can be adopted only when the grasping surface is without hollows, while the second one fits the grasping specifications. Actually BIBA developed a two fingers friction grippers with fingertips consisting of very tough textile tubes filled with plastic grains. The tubes are connected to a vacuum pump and they can be inflated or air can be evacuated. When the two fingertips are moved to the batch the grains will be displaced and the tubes fit the shape of the batch. After the contact with the tiles, the tubes are evacuated and the fingerpads remain frozen. In this way the relative motion of the bricks and hits among them are prevented.

5. Conclusions
At the present moment the system adequately defines the grasping principles capable to perform the required operation together with some fundamental recommendations. However, finding a way to evaluate every possibility, including the variability of the objects, still requires further study and work that could be done iteratively. Since the system is based on a set of rules that can be easily updated, in future it could work as a self-learning system. This turns into an increase in terms of effectiveness and efficiency.

5.1 Future works
At the present, the system shows how the lack of detailed and standardized gripper data represents the main drawback. A standardized methodology for describing gripper characteristics and collecting enough data to build a complete and vast gripper database will be the main goal of future developments. The presence of an extensive database, which includes even industrial grippers currently available, would allow to establish a ranking based on different requirements, such as costs, time and reliability, in order to better meet the user’s needs.

Another future necessary step is the implementation of an expert system into a commercial shell. Rules have been already written in formal language in order to facilitate this process. The software implementation would also allow to increase the reliability of the system when new rules are introduced, since it easily allows a cross-check between parameters and rules.

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