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Self Adaptable Clamping Tools for Multiple-Seizure

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Abstract

In process clamping and handlimg, it is often required to grasp, with the same gripper, objects having different shape and size. The paper introduces out-fits, studied to solve this problem. Both, the articulated clamp and the clamp with flexible elements can automatically adapt their shape to grasp rigid and deformable objects; both principles has been tested with prototypes. Of special interest is the clamp with flexible elements; this solution, at the same time, presents an easy design and performs a firm and safe grasp. Next, as example application, an underwater cutting robot that adopts the latter gripper is presented. Finally, the potential impact in the industry of these devices is considered.

1 Introduction

Robotics hands [1, 2, 3 and 4] offer high dexterity but are not used in the industry due to their high costs, low grasping forces, high complexity and limited reliability. It could be interesting to find a “class” of grippers more smart than classic grasp/release clamps and less dexterous and complex than the robotic hands. It is crucial to stress that these “almost smart” devices work properly only under restricted conditions. These boundary conditions shall be considered during the planning phase; the whole industrial process and, hence, the robot task have to be simple enough, to allow the grasping tool to work properly. The seizure of a single object is, by itself, delicate; the demand to use the same grasper for different objects increases the task difficulty. In general, the resort to the same grasper for any sort of objects and every environment (anthropomorphic hand) has very little industrial meaning; instead, effectiveness needs to deal with assorted sets of objects, with known shape and size variability, without changing the effector, rather, simply adapting the engagement procedure.

2 Clamp design

An “almost smart” clamp has 1 DoF and recognition capabilities; once the clamp is positioned in contact with the object to be grasped, it autonomously recognises the profile of the object and adapts its shape to better seize it. Three examples of clamping devices are presented: a basic clamp and two “almost smart” fixtures. Each of these devices (figure 1) uses a different work principle: shape clamp (nut cracker), articulated clamp (fingers), clamp with deformable elements (lasso).

Figure 1. Types of clamps.

2.1 Shape clamp.

When a shape clamp is used, it is necessary to know the shape and the dimension of the object to grasp. For example, the two arms of the nutcracker are shaped to host the nut and cannot grasp an hazel-nut. During the grasp, there is a sort of recognition shape object to grasp/shape of the clamp. A clamping tool powered by hydraulic arms (figure 2) is classic example of shape clamp. The frame of the rover clamping tool (part 2), is anchored to the object to clamp (part 1), by means of two clamps (part 4 and 5). Each clamp can rotate around a pin (part 6 and 7) and is powered by ram (part 8 and 9). The cradle of the clamp (part 3) is in contact with the object. Each clamp applies a local force against the outer surface of the object.

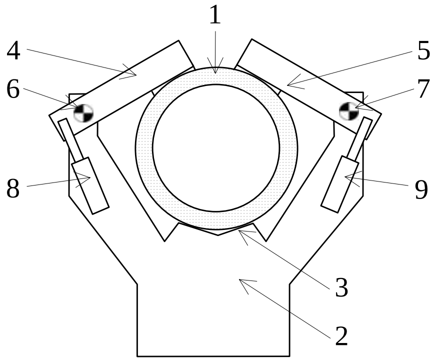

Figure 2. Basic clamp.

This solution offers a firm grasp, is easy and robust, but has the disadvantage to be not general. Each time it is needed to clamp, e.g., pipes with different diameter, the clamp geometry has to be manually reconfigured; this re-fit is necessary, because each piston, while the clamping tool is closed, must form 90° with its clamp, to transmit the overall hydraulic torque around the pin. The clamps have to satisfy the following constraints: - they do not have to touch each over (they are coplanar); - they must touch the object in suitable points to guarantee firm hold. A tool, with the same clamps, can seize only a limited range of different items. For example, in the domain of the underwater robotics, to secure a rover on 8 to 36 inches structures, it is necessary to own a set of at least 5 or 6 different clamping tools. Before diving, known "a priori" the diameter of the structure to clamp, the rover shall carry the relative clamping set.

2.2 Articulated clamp.

When it is requested to grasp, with the same clamp, objects of different size and is not possible to manually adjust the clamp settings, the classic shape clamp cannot be used. As stated before, a robotic hand is at the same time, too complex and dexterous for most of industrial applications; may be a robotic finger can fit better the task. The articulated clamp is a sort of finger (figure 3).

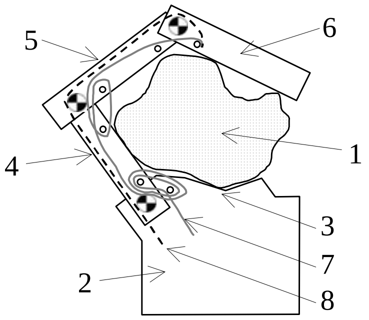

Figure 3. Articulated clamp.

As for the shape clamp, first it is necessary to put in contact the object (part 1) with the clamp palm (part 3). Then the finger *automatically* disposes itself along the profile of the object and grasps it. The mechanism is actuated by two antagonistic tendons (party 7 and part 8); while the tendon for the closure (part 7) is commanded, for example by a winch, the clamp opening is a passive movement, for example actuated by an elastic tendon (part 8). The finger is formed by a sequence of segments (part 4, 5 and 6). The clamp closure tendon (part 7) has two extremities: one, secured on the last finger segment (part 6); the other, pulled inside the clamp frame (part 2). The tendon 4 passes times between the clamp frame (part 2) and the first finger segment (part 4), passes 2 times between the first and the second finger segments (part 4 and 5) and passes only one time between the second and the third finger segments (part 5 and 6). Due to this pulleys set-up, when the tendon is pulled with a force $F=F_o$, the segments 1, 2 and 3 receive respectively a closure force of about 4 F_o, 2 F_o and F_o; more exactly these forces are function of the segments geometry and of the angles frame/segment 1, segment 1/segment 2 and segment 2/segment 3. This embodiment allows a correct finger closure (figure 4). Naturally, first segment 1 has to be driven in contact with the object, then segment 2 and finally segment 3.

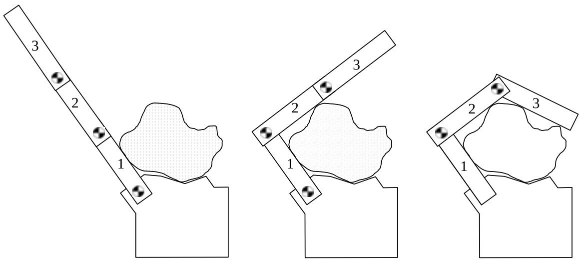

Figure 4. Grasping procedure.

A Lego® prototype of the articulated clamp has been built; the performance of the clamp was satisfying. The real model has shown the clamp limitations; as expected, the grasp is secured only if the relative friction between the object and the segments is high. Moreover the pulleys architecture has some drawbacks. During the grasping procedure, the object to clamp must be fixed respect to the cradle; once the segment 1 is in contact with the object ($F=4\ F_o$), the segment 2 approaches to the object ($F=2\ F_o$) only if the object is able to react against the segment 1 ($F>4\ F_o$). Else the movement of segment 1 pushes the object away from the cradle. In the case the object is big respect to the clamp (and it is necessary to secure the clamp on the object), the problem is negligible. Another drawback is that the force between the finger and the object is not constant; each segment exerts on the object a different force. To solve this problem, it is possible to create a clamp having two fingers. The minimum size of the object that can be grasped by the articulated arm is function of the number and of the length of the finger segments.

2.3 Clamp with flexible elements.

The clamp with flexible elements has been designed to simplify the shape of the articulated clamp. Like the previous clamp, this clamp can be used when it is needed to clamp a rigid or a deformable object. The pressure applied by the clamping tool on the object can be easily changed, making the clamp suitable even for manipulating soft or delicate objects. The clamping tool with flexible elements is able to replace the whole clamping set of clamping tools with shape clamps; the same clamp can grasp, for example, structures from 0 inches to 36 inches. This mechanism has a structure similar to the shape clamp and a working principle similar to the lasso. Once the lasso is positioned around the object to clamp, the lasso rope is tightened. The rope of the lasso, thanks to its deformability, is able to copy faithfully the contour of the object. A clamping tool with three flexible elements (figure 5), is now described. Three clamps (figure 5a, part 4 and 5, figure 5b, part 1, 2 and 3), are linked to a frame (figure 5a, part 2), provided with a cradle (figure 5a, part 3); each clamp can rotate around a pin (figure 5a, part 6 and 7). A flexible element (figure 5a, part 10 and 11, figure 5b, part 4, 5 and 6) is linked to the free extremity of each flexible element. The second extremity of the three flexible elements is linked to a stretching system, for example a winch (figure 5a, part 12), positioned inside the frame. A pin (figure 5a, part 13) forces the flexible elements to be in strict contact with the element to grasp (figure 5a, part 1). As shown from the side view (figure 5b), the flexible elements are located on different planes (figure 5b, part 4, 5 and 6); each flexible element exerts pressure on the object.

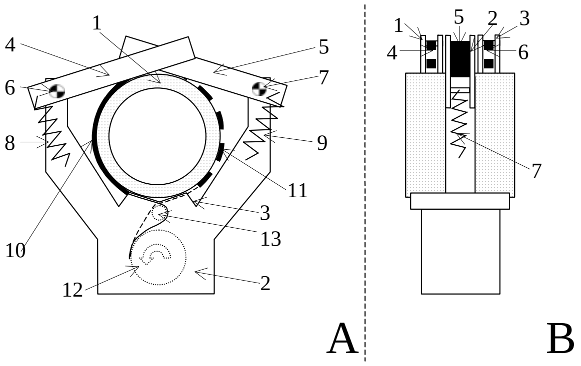

Figure 5. Clamp with flexible elements.

On the cradle reaction forces born to balance the resultant of the forces applied by each clamp on the object and by each flexible element on the object. The winch (or winches) has the task to tighten the flexible elements and than to close the clamp around the object; the opening of each clamp is acted by a spring (figure 5a, part 8 and 9). The figure 2 shows the working principle of the clamping tool; the real position of one of the release springs is shown in the figure 3 (figure 5b, part 7). It is now described the grasping procedure of the clamping tool with flexible elements (figure 6).

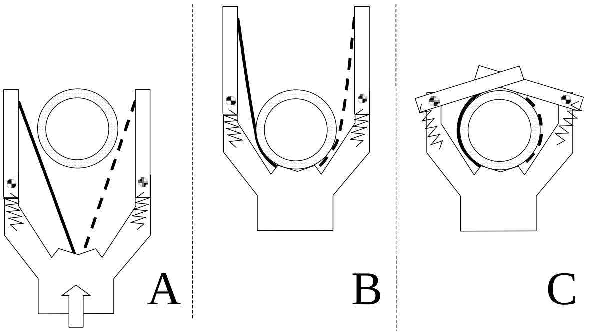

Figure 6. Grasping procedure.

While the clamps are parallel each other (figure 6a) and perpendicular to the cradle, the clamping tool is brought near to the object to grasp untill the object gets in proximity or contact of the cradle (figure 6b). Then the winch (or winches) is powered; the torque of the winch (or winches) is used, initially to close the clamps, after to secure the grasp (figure 6c).

The torque applied by the winch (or winches) determines the grasping force. The flexible elements, during the movement of the closure of the clamping tool, create a sort of lasso that tightens until it finds the profile of the object (figure 7). The synchronised movement clamps/flexible elements, positions the object in close contact with the cradle, and centers the object respect to the cradle. Unlike the articulated clamp, in the case of the clamp with flexible elements, there is no limit about the minimum size of the object that can be grasped.

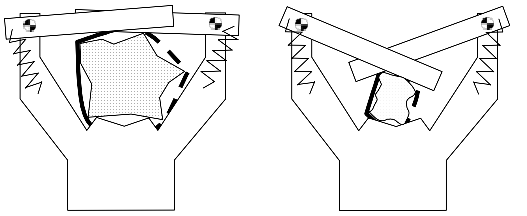

Figure 7. The lasso grasp.

While for the shape clamp (figure 2) and for the articulated clamp (figure 3), the grasp clamp/object is performed by a limited number of contact points, the grasp flexible elements/object (figure 5) is exerted along the whole profile of the object. A distributed grasp is more delicate than a single points grasp, as the object, instead than by local forces, is held by a pressure. Each clamp with flexible elements can grasp objects having a huge size; it is possible, for example, to build a clamp with flexible elements able to grasp structures from 0 to 30 inches. Depending on the kind of application, it is not suitable to use a clamp larger than 30 inches to grasp structures as small as 4 inches. To face this problem, a clamping tool with flexible elements having a variable width (figure 8) was designed. The parts of the frame that sustain the clamps (part 1 and 2), are mounted on sliding guides (part 3 and 4). A system of fast fastening (part 5 and 6) allows to regulate manually the width of the clamping tool.

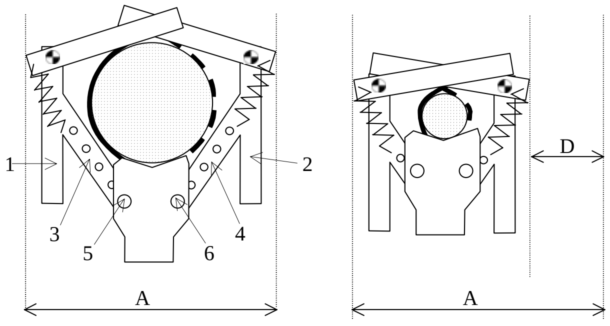

Figure 8. Variable width clamp.

The width of the clamping tool with flexible elements and variable width is decreased when there are problems of clearance, to increase the clamp handiness and for the transport. Like for the articulated clamp, a Lego® prototype has been produced to test the clamp performance. The clamp is able to compensate some misalignments errors of positioning of the clamp respect to the object; even if the object to grasp is initially not in contact with the cradle and not centered respect to the cradle, the flexible elements will automatically push it against the cradle and will center it. The prototype we built has two flexible elements; these elements need to have exactly the same length to provide a symmetric and balanced grasp. Because of the flexible elements lay on two different planes, the forces they generate on the object create a moment (function of the distance between the planes); this moment tends to create a relative rotation between the clamp and the object. The cradle is able to compensate this effect, generating an opposite moment only if it is in good contact with the object; for this reason the cradle has to be designed wide and "comfortable" enough to offer a good object match.

3 Example developments.

It is possible, for example, to use a two flexible elements clamping tool with variable width, to execute submarine cuts with diamond wire (figure 9); for sake of clarity, the two return springs are not shown. Typically, the task requires to secure the object to the clamp, or to the clamp to the object. In this case, the clamping tool of the underwater rover has to be tighten to the structure on which operate (for example a pipeline).

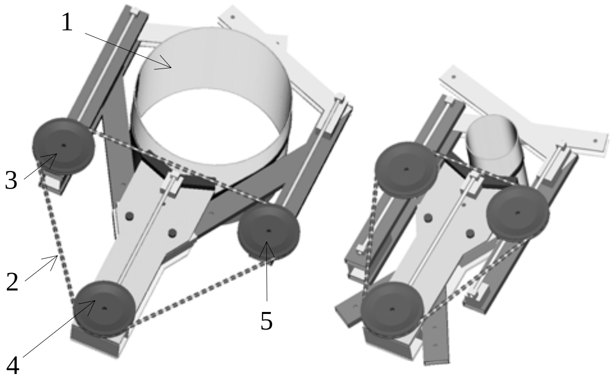

Figure 9. Underwater cutter.

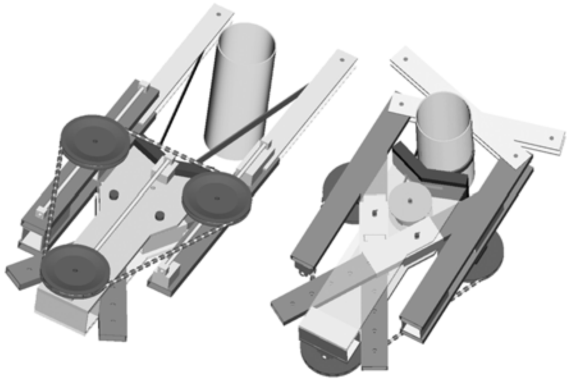

Figure 10. Frame detail.

This application can be considered as an evolution of the patent WO02075059 "Method and apparatus for cutting underwater structures" of Matteucci Francesco, Tecnospamec Srl It. The original hydraulic pistons shape clamp of the patent is replaced by the clamp with flexible elements. Once the cutting machine is secured to the structure to cut (part 1), the structure is cut using a diamond wire (part 2) that rotates around pulleys (part 3, 4 and 5). One or more pulleys are powered. All the pulleys are mounted on sliding guides (not shown in the picture); during the cut, the diamond wire is slowly brought on the object to cut. For a more detailed description of the cutting process, it is advisable to consult the patent WO02075059. Figure 10 offers a closer view of the underwater cutter frame; as in figure 9, (again, the return springs are not given).

The flexible element could be, for example, a band of rayon fabric or a steel wire. The figure 11a and 11b offer a detail view respectively of the position of the flexible elements during the grasp and of the fast fastening for the clamp width set-up.

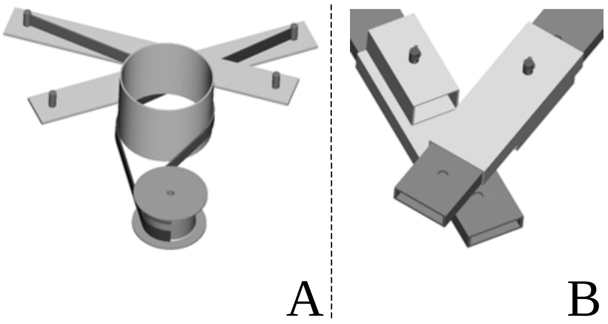

Figure 11. Clamp details.

4 Concluding comments

The working principle of both the articulated clamp and the clamp with flexible elements has been tested and validated by Lego® prototypes. Specially innovative is the clamp with flexible elements (patent PTC/EP03/51098, priority date 20/06/2003); thanks to its easy architecture and clamping capabilities, it can be used in several fields. Not limitative examples are the industry, the robotics, the building, the medicine etc. More specific fields of application are; lifting with cranes, underwater operations, micromanipulators, surgical operations.

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