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VISION BASED ASSISTED OPERATIONS IN UNDERWATER ENVIRONMENTS USING ROPES

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Abstract

This paper faces up the problem of carrying out simple tasks, such as to fasten an object, tasks that become relatively complex operations using robots, specially in underwater environments. The goal of this work is to perform such tasks by using intelligent strategies that planned step by step allow to compensate the robots own limitations. The strategy is based on the use of information from stereo vision and the required auxiliary devices or tools to contribute to the development of the task.

1 Introduction

The need to develop works in underwater environments has lead to the development of underwater robotics. Many works carried out up to now have been addressed to applications such as exploration, maintenance and surveying [1], [2], [3].

Much effort has been done in the development of systems and tools to carry out actuations undersea. The accomplishment of these tasks carries with it in many cases, the need to use robotic arms with 5, 6 or even more degrees of freedom (d.o.f), endowed with dextrous hands and sensors [4]. But, it would be possible to perform some such tasks using simpler arms, with less d.o.f, at the expense of introducing new more intelligent strategies. The project Garbí [5], has been developed in this direction, the construction of a low cost ROV (Remote operated vehicle), that allows to perform certain number of tasks such as samples collection, inspection or manipulation of small objects. This ROV has two articulated arms with low actuation force and only three d.o.f each (Fig. 1). In order to solve the grasping difficulties produced by the lack of degrees of freedom at the wrists of both arms, the grippers have been arranged with different orientations; one vertical and the other horizontal. This grippers arrangement forces the use of only one of the two arms for grasping while the other is uniquely auxiliary for the task. Which function each arm adopts depends on the layout of the elements to manipulate.

With this prototype, having such constraints, the execution, by means of teleoperation, of relatively simple tasks become very difficult and it requires great ability from human operators.

To easy the execution of some tasks, by means of ropes coming from the capstan of the support ship, as it is the case of objects or parts manipulation or retrieval, we have developed a semi-automatic vision based control system. This control system is conceived to perform tasks such as:

- to pick up a rope
- to surround an object with a rope
- to hitch a rope with a hook
- to hitch a ring with a hook

The aim of this work is to study the way to face up the dexterity and power limitations of current underwater robots by looking for intelligent strategies that make these tasks possible [6], [7].

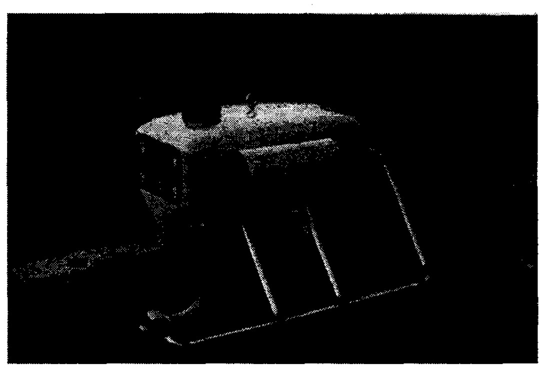


Figure 1. Garbi prototype

2. Tasks characteristics

The manipulation tasks that use to be carried out over solid objects in underwater environments are:

- *Positioning*: To let an object on the sea bottom or on its site.
- *Retrieval*: To hoist something from the sea-bottom or from its site.
- *Moving, transferring*: To move an object from its original site, to follow trajectories free of obstacles or to move through obstacles.
- *Turning*: To modify the object position by rotation over its axis, or over other directions to orient it in space.
- *Observation*: Usually obtention of video images.
- *Machining*: To carry out some operation such as screwing, cleaning, drilling, welding...
- *Joining*: To perform different kind of connections such as coaxial joins, or insertions.

The execution of such tasks, that require to move objects or their retrieval, is very frequent. These tasks can not be directly performed with the ROV arms due to the high forces that would be required. But on the other side, these forces could be carried out by means of the traction of a capstan from the support ship.

Consequently, a semi-automatic system to control the robot arms has been developed. To execute some concrete actions the tasks are carried out with the aid of a rope externally controlled. The user is required to only define the goals, to initiate the robot arms manoeuvring and to abort it in case of failure, that is, whenever the operation does not progress as previously expected.

The control system is in charge of the control of certain tasks such as: to pick up a rope, to encircle or to hook an object. It has to control the two arms in co-ordination, from the images information obtained by the vision system.

3. The vision system

The underwater vehicle, Garbí, is provided with a stereovision system that processes the images obtained from two cameras oriented towards the arms working area. The processing algorithm supplies the position of certain relevant elements in the 3D scene. So as to be able to perform automatically the task of manipulating the rope, the stereoscopic vision system developed performs basically the following tasks:

- Scene segmentation for rope detection, based on the analysis of the image histogram.
- Determination of the 3D rope position. This data is calculated from the rope boundaries using stereovision. We use the epipolar constraint to determine homologue points in the two images in non-ambiguous rope segments.
- Local texture analysis to solve the overlapping problem. This analysis is necessary since 3D data is not precise enough, due to digitising errors, to distinguish the rope segment above from the one below in a crossing point.
- Generation of highlighted images to help the human operator to interpret visually ambiguous relative distances between the rope and the robot arm.

3. 1 Rope location

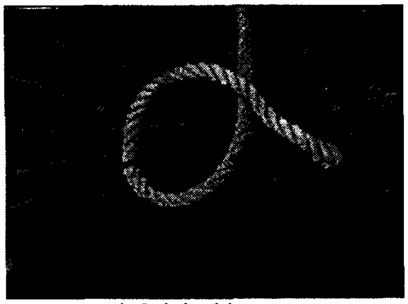
The execution of the tasks requires to locate the rope position to determine the adequate grasping points and to decide the actions to carry out. The method used to locate the rope, as shown in fig. 2 consists of different steps:

1. The image is binarised using a floating threshold.
2. Since the working image is expected to not cover all the rope length, we start the searching of the rope entering point in the image periphery, fig. 2b.
3. To locate the whole visible rope, the algorithm starts a tracking process from the first rope point in the image border and then tracks the rope all along its visible length. The tracking starts using a window that has the same format as the initial window, and only an increment of ± r pixels in the window size is allowed at each iteration, fig. 2c. (In this case r = 0).
4. The search of the next texel is done by correlation of the neighbour windows. When more than one neighbour texel is similar to its predecessor, as happens in a crossing point, the one that better maintains the previous direction, (an average of the three previous texels) is taken (Fig. 2d).
5. After passing a loop, the algorithm again juxtaposes a new window where it founds the maximum number of white pixels (Fig. 2e).
6. Once the tracking is finished, the algorithm searches for new rope segments not tracked yet, starting in the periphery, until no more points are found.

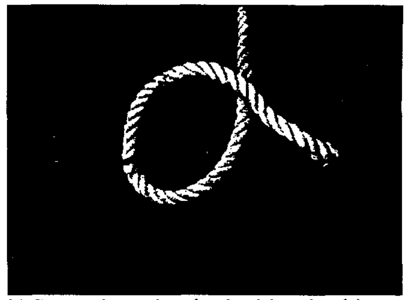
3. 2 Overlapping ambiguity in loops

The algorithm for rope detection does not distinguish, in rope overlapping points, whether a rope segment is over or below. It only tracks the rope all along its length. To solve this ambiguity the rope texture is analysed based on the contour information. Fig. 3a shows the rope contour image.

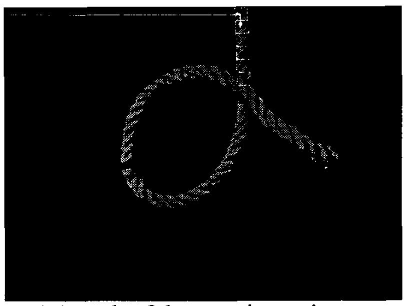
The first step to solve this overlapping problem, not solved by the depth calculation of the rope segments in a crossing point, is to analyse the texture within the two windows, or texels, the anterior and posterior to one intersection. The texture measure is based on the analysis of the contours direction in each texel.



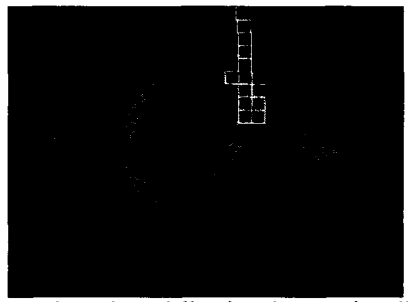
a) Original image



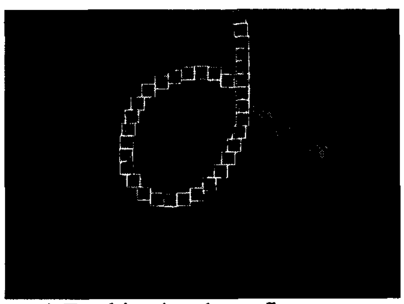
b) Rope detection in the binarised image



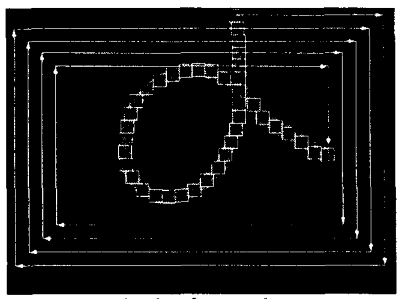
c) Search of the entering point



d) Crossing a loop following the entering direction



e) Tracking in a loop, first run



e) The detected rope

Fig. 2 Image processing for rope location

The first step to solve this overlapping, not solved by the depth calculation of the rope segments in the crossing points, is to analyse the texture within the two windows, or texels, the anterior and posterior to one intersection. The texture measure is based on the analysis of the contours direction in each texel.

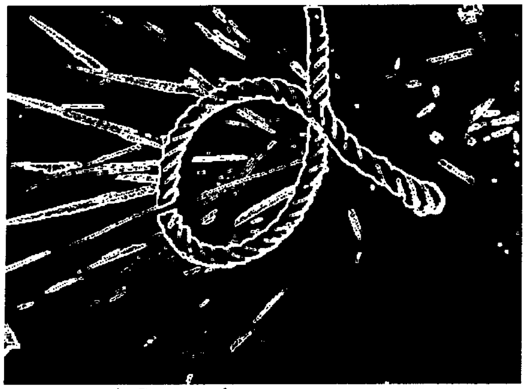
Next step consists on correlating the contours information of the windows entering and exiting an intersection with respect to the intersection windows, (fig. 3b). The similarity or dissimilarity among the texels around a crossing point determines which pair of texels maintain a continuity with the crossing visible point, the upper one. Fig. 3c shows the tracked rope, applying this algorithm, with indication of the above and below parts.

The rope continuity line, indicated in the image, is completed calculating a polynomial function passing through four consecutive texel centre points.

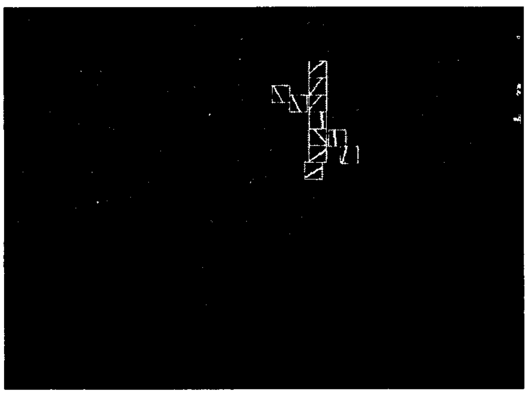
Fig. 4 shows the results obtained from the detection, location and tracking of ropes with different windings and the determination of their continuity or discontinuity in loops or crossings.

4. Underwater objects manipulation using ropes

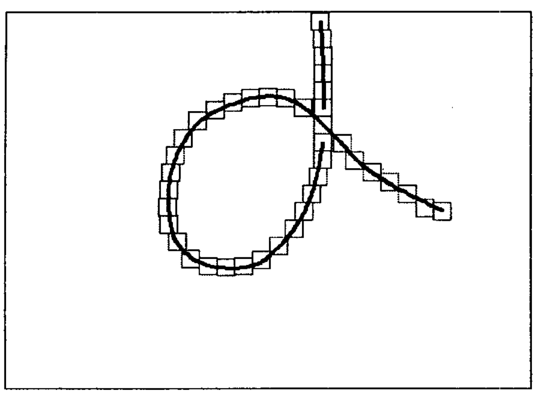
To plan the manipulation of objects the starting information consists of, on the one hand, the data provided by the vision system, and, on the other hand the definition of the tasks objectives.



a) Contour image



b) overlapping solving by texture analysis



c) final tracked rope

Figure 3. Rope location and solving of overlapping ambiguities.

From the above mentioned underwater common tasks we have studied the degree of difficulties in planning and executing some of them using ropes, taking into consideration both sensing and dexterity aspects.

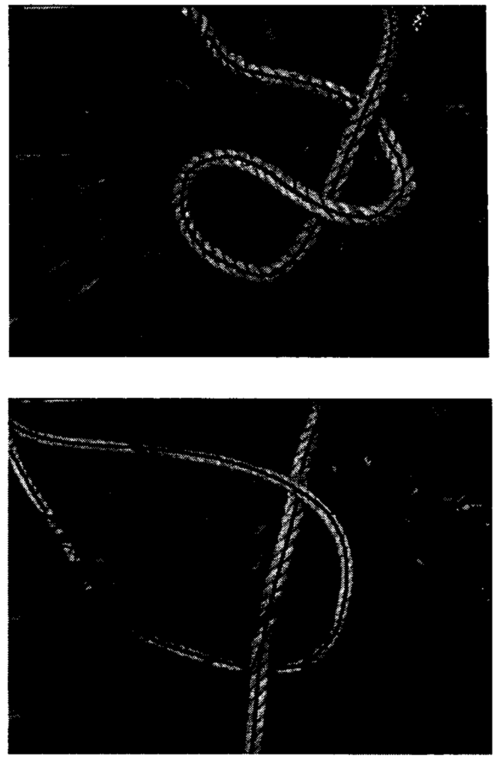


Fig. 4 Examples of ropes detection and location

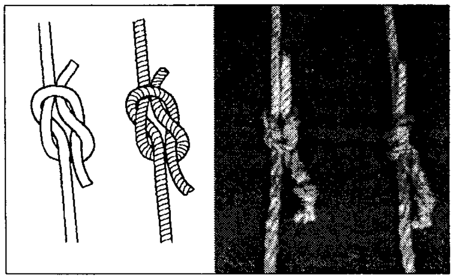
4. 1 Task definition

The use of ropes implies the possibility of tying knots or performing simpler operations when specific auxiliary elements such as hooks are available.

The interpretation of scenes containing knots, in most cases twisted ropes, results to be specially difficult due to their texture.

A very frequent knot, the reef knot, is not ever as evidently interpretable as it is shown in fig. 5a., where it is drawn as an ideal knot. Reef knots usually appear as shown in fig.5b, where it can be appreciated how the rope texture difficult the clear vision of the knot itself. Another difficulty is demonstrated in fig.5c, where the knot orientation is not orthogonal to the vision plane.

To this difficulty we can add those derived from the own knots execution, not only in what refers to emulate the task carried out manually, with five dextrous fingers in each hand, but also due to the forces that have to be applied to tie a knot, and even more those required to loosen it. In the Garbí project we renounced, on the one hand to perform knots, and on the other hand to have dextrous hands.



a) b) c)

Figure 5. Different views of a reef knot. a) an ideal knot, b) a realistic knot, c) a not orthogonal orientation

After these considerations, the task proposed to be performed is to surround and hold a solid object (Fig. 6) and by hitching it with a bow with the aid of a hook.

4.2 Vision aids for teleoperation

To perform the above mentioned tasks, the human operator needs to perceive the scene in 3D. Instead of visualising a 3D scene, requiring the use of stereo glasses, the vision system supplies graphic indications to highlight the image. Over the rope, a colour coded line which colour intensity depends on the distance, provides, at the operator will, the required depth information.

A second visual aid consists on showing, when required by the operator, in the highlighted image, the estimated arms and grippers position, when they are occluded by an object in the scene

To ease the teleoperation task, the data used to feedback information about the robot position are those corresponding to the master arm encoders instead of those measured from the vehicle arms. Thus, the delay due to communication but mainly to execution time is avoided and consequently the stability problems are greatly reduced.

4. 3 Hoisting strategy

Different hoisting strategies can be used for parts retrieval depending on the characteristics of both, the ropes (standard or hook ended) and also of objects or parts (perforated object, object with a hook, or compact). To hang perforated objects, the robot has to pass a rope end through the object hole or bow. The robot can be automatically guided from the data provided by the vision system.

In the case of compact objects, for instance pipes, the task to be performed is more complex. The robot arm has to surround the object with the rope, and to close the rope loop by hooking the rope hook into the own rope.

We have focussed our work to solve this later problem. To compensate the robot low number of d.o.f., the robot arms are also provided with a fixed hook, a passive support element. The function of these hooks is to hold the rope so as to easy the pulling movement and the rope location. The steps to be performed to complete the robot task for a hoisting operation are described bellow.

1. To grasp the rope hook end with the left gripper, being the rope end position provided by the vision system.
2. The left arm pulls the rope towards the right arm and passes it through its hook, then this arm grasps the rope hook.
3. The right arm pulls the rope surrounding one half of the object, while the left arm approaches the same point from the opposite direction
4. The left gripper grasps the rope hook from the right hand. At this point there is no visibility, but the hands position are defined by the arms configuration.
5. The left arm pulls the rope through the second half of the object.
6. The left gripper hangs the rope hook in the rope section located on the hook of the right arm
7. Left gripper frees the rope from the hook of the right arm.

Some of these steps are more critical than others mainly considering the underwater environment, marine currents and so, where they are carried out. Steps 2, 4 and 6 present special difficulties. In step 2, the precision required to pass the rope through the arm hook can cause failures and to force to start again this actuation, it is also critical that the rope keeps on the hook all long the sequence. In step 4, the object to be removed does not allow the vision system to see the grippers. Thus, during this action there is no sensorial feedback about the correct

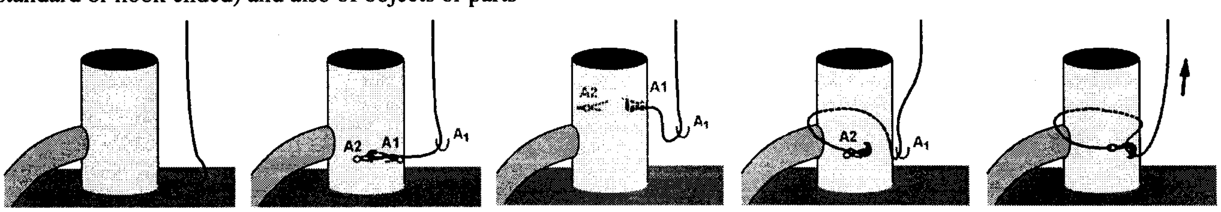


Figure 6 Schema of the task

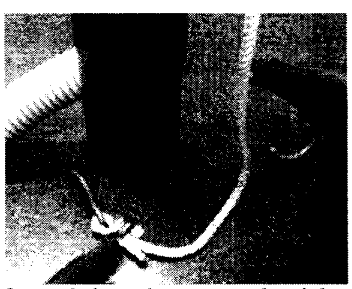
execution of the end rope exchange between right and left grippers. Finally, a difficulty to execute step 6 is that undersea currents can move the rope and make difficult also to hook the rope hook on the rope itself. Figure 7 shows a successful sequence of the operation of fastening an object for its retrieval.

4. Conclusions and results

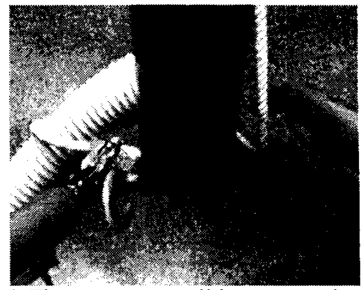
The use of hook ended ropes enables to fasten undersea rigid objects using simple arm structures and carrying out the corresponding operation strategy. An alternative to the use of hook ended ropes is to fasten the object by tying knots, using a standard rope. In this case, the actions to be performed to tie a knot are more complex and require an arm structure with a larger number of degrees of freedom and higher payload.

The experimentation in performing the fastening operation by teleoperation from the surface, even using hooks, has shown to be very hard and with a very high rate of failed trials. The use of the two robot arms working semi-autonomously, supervised by the human operator, has increased enormously the efficiency. Nevertheless, the semi-autonomously, supervised by the human operator, has increased enormously the efficiency. Nevertheless, the environment conditions and robot arms simplicity makesit no possible to avoid the human supervision. This requirement is not so bad for such applications since the human operator is necessarily there to control the rest of the part or object retrieval task.

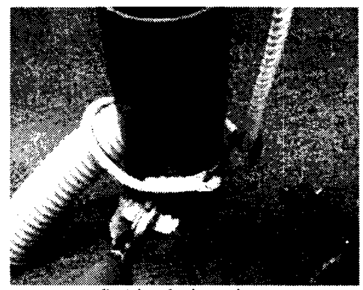
a) Initial situation



b) The left arm brings the rope to the right arm hook



c) The two arms pull in cooperation the rope around the object



d) Final situation

Figure 7. The robotised fastening strategy.

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