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DEXTERITY IMPROVEMENT IN TELEOPERATION THROUGH COMPUTER VISION BASED AUTOMATIC CORRECTION

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Abstract: Robot manipulation through teleoperation requires some ability from a human operator. This requirement is stronger when the tridimensional scene is observed through a 2D monitor. This paper describes a telemanipulation aiding system based on the superposition of a position correction component to the manual orders given by the human operator, through his gestures. This correction will enable the slave arm to move quicker when it is far from the target, while moving slower and more precisely when it operates close to the target, thus, the system behaves as if an external attraction force appear around the possible objects to be manipulated. *CopyrightÓ 2002 IFAC*

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1. INTRODUCTION

The widening of robotic applications from the industrial environment to the wide services sector, including areas such as medicine, maintenance, exploration, etc... opens new control and perception problems not solved with current technology. These new application fields, in which robots operate in “natural environments”, that are consequently unstructured, unknown, etc., has propitiated the use of teleoperation, as the means to add the intelligent human decisions in the robot control loop, thus, making robots much more efficient.

Due to this robotics expanding applications, it is necessary to have available teleoperation aiding systems to increase the efficiency on the execution of relatively simple tasks, such as grasping an object or fastening a hook, specially when such tasks are carried out remotelly. Some of the problems detected, for instance in tasks of insertion parts as described by Debus et al. (2000) are: low clearance, little accommodation when using hydraulic actuators and poor sensing information feedback (vision and force). Delays also constitute a significant problem in teleoperation.

The goal of the present work, is to provide such teleoperation systems with some aids that facilitate the task of manipulating the target, or environment elements, with enough precision. Therefore, we approach the concept of semiautonomous, or shared control. This kind of control derives from the concept of supervised control proposed by Ferrell and Sheridan (1967) to solve the above mentioned delay problem. Some examples of this kind of control in teleoperation can be found in the work of Boissiere and Harrigan (1988) oriented to obstacles avoidance, or in that of Kim, Hannaford and Beckzy (1991) that address the delays problem. With such control, the operator can concentrate himself on the planning of the global teleoperation task while an obstacle avoidance planner modifies the commands of the operator, as shown in Lumelsky and Cheung (1991).

This concept shows some analogies with the concept of attraction forces and potential fields. Attraction forces generated from sensing the environment or from data coming from environment models are used in different kind of applications, to improve the performance, both of autonomous robots or teleoperated manipulators. The methods based on potential functions such as electrostatic or Newtonian fields have been extensively studied for path planning through obstacles. Some of this works can be found in Hwang et al. (1988), Chuang et al. (1991) and Hwang et al. (1992). In the works of Barraquand et al. (1992) different numerical potential field techniques based on the use of pyramids to represent the robot working space in the configuration space are described. The work by Vadakkepat et al. (2000) combines a method of artificial potential field with genetic algorithms. Operating with robotic arms, several applications of such attraction and repulsive forces can be mentioned. For instance, in the research work of Chong et al. (2001) a virtual repulsive force is generated to prevent the possible cooperative robots collision, which could be produced due to teleoperation delays, while in Turo et al. (2000) attraction and repulsive forces are generated to provide certain haptic perception to the human operator, an attraction force when the robot moves towards the goal and a repulsive force when the robot approaches a singularity.

Yokokohji et al. (1993) proposed different operation modes for the addition of functions to the remote teleoperation signals and introduced a coeficient to determine the weight of each of them. Tarn et al (1995) proposed a method of shared control in hybrid (force-position) control systems, with the aim of avoiding obstacles and coordinate two robot arms. Aigner et al. (1997 and 2000) studied the integration of a human operator in the control loop of discrete event systems using strategies based on potential fields, oriented to minimise human errors.

Teleoperation tasks require the use of strategies that guide the operator when the precision and dexterity for succeeding in a given task is not achievable by the user alone, mainly when working under adverse operation conditions. For instance, when sensorial feedback is poor. In general, this guidance requires high precision when the arm operates close to the target, but at the same time, the operator should have high controllability of the task.

The aiding system developed follows the principle of adding two functions, the composition of two input signals, one supplied by the human operator and a second one, a correction factor, produced by a sensor based system. The main aim of the work is to provide the master-slave control unit with a vision system that generates the data necessary for aiding in the guidance of the slave arms towards the relevant objects on the scene. With the idea of increasing the precision of the movement when operating close to the target, the method proposed performs a topological transform of the working space coordinates system, in function of the distance of the end-effector to the target. In this way, the system behaves in such a manner that when the operator moves right towards the target, the movement is easy. But, the movement will find difficulties, altering the manipulator speed, when the teleoperated orders are not directed towards the target.

The generation of the correction function is a function of the position and shape of the visible objects. The objects having shapes adequate to be grasped or tighten, according to the phase of the manipulation process, are those that produce the effect of facilitating the movement.

Thus, the paper first describes the way of characterising the objects so as to decide the robot guidance assisting function. After a brief description of the procedure for image segmentation in 3D, we define the method used for the generation of the position correction function, or better, the topological transformation.

2. OBJECTS CHARACTERISATION

With the aim of providing the user with some support in the execution of manipulation tasks a first aid consists in the determination of the objects position. A vision system is used to detect the desired object, generating from the image segmentation a virtual potential well, which is placed in the centre of gravity of the object that is located closer to the point where the teleoperated arm stops, or pass by.

Looking deeper at the process of manipulation and grasping, we have studied a procedure to determine, depending on the object's shape, the points more adequate for the object to be grasped, inserted or manipulated. From this study, the topological transform in the operating space, so as to improve the telemanipulation task is determined. For instance, a circular shape would have to facilitate the movement towards its centre, like a physical attraction towards this point, making an insertion task easier. On the other side, a linear shape would produce a uniform effect all along its length, making contouring tasks easier. Fig. 1.

Since the manipulation operation will be carried out in a 3D environment, the visual analysis of the curvatures and typology of the different elements in a scene is performed by means of a stereovision system.

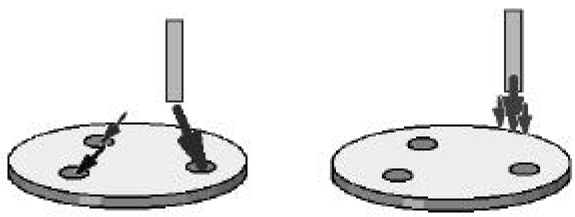


Fig. 1 Two working scenes with indication of the attraction effects of the telemanipulation position correction function. a) in insertion tasks, b) in contouring tasks

3. TOPOLOGICAL TRANSFORM

The topological transform implies the definition of a variable resolution distribution, a deformation, in the working space, with respect to the uniform distribution in the operator space. The goal of this transformation is the generation of different behaviours in the command of the slave manipulators, that obey the operator's orders, but responds different depending on the distance of the end-effector to the potential target elements, and their characterisation. This concept is shown in fig. 2, in a one dimensional space. The operator works in a Euclidean space, while the slave arm operates in the transformed space. In this last space, a high concentration of lines (or pixels) is observed in the origin (the target point), and a dilatation progresses when going away from it. At further distances the spatial density recovers its original uniform density.

From this image, it can be observed that when an object travels at constant speed in the Euclidean space, towards the origin, initially, the travel speed will be constant, when approaching the target, the speed will increase, but with low resolution. Finally, when the object gets closer to the target, the space contracts, reducing the object speed, that is, a given movement in the Euclidean space will produce a smaller displacement in the transformed space. It can be seen as a speed reduction in the transformed space, but with a higher precision, as if it were attracted by the target.

4. IMAGE SEGMENTATION

The characterisation of the objects that appear on the image of the working scene starts with an image segmentation step. This image processing is carried out from the images acquired by the same cameras used by the visualisation of the working space. The goal of the image segmentation process is the determination of the position in space of the objects present in the scene, and from their shape the correction function is computed.

Classical segmentation methods are usually based on colour, movement, or texture. Due to the lack of contrast or low quality of images usually available when working in natural environments, those where services robotics must operate, movement information can improve the segmentation process when applicable.

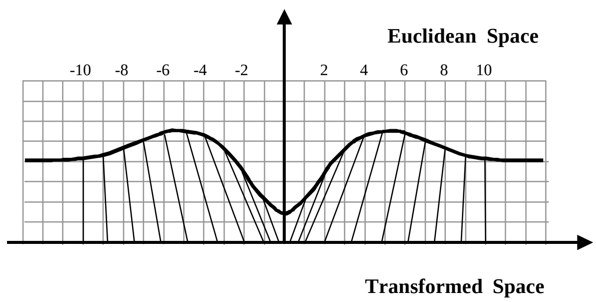


Fig. 2 The topological transform in a one dimensional space

From the segmented image, the next step is to extract some features for stereo matching. Common methods for features extraction are based on local features, local correlation or colour boundaries. Working with low quality images images, the method that has given better results is based on the matching of contour segments, that are considered the most contrasted features of the image. The algorithm for contours extraction uses a variable threshold. The criterion for threshold computing is the maximisation of the correlation function between homologue contour segments in the two stereo images, with the aim of making the stereoscopic matching process easier. The matching carried out by means of contour segments, or micro-matching, has become highly robust and provides a precision higher than that obtained from the methods based on point to point correlation. This work is an extension of previous work of our group as described in Amat et al (1997 and 1999)

Segmentation in real time makes possible the use of the obtained data in the control loop.

5. THE TELEMANIPULATION ORDERS

Based on the fact that in the services sector the operations to be carried out are very varied, they can require different robot performances and dexterity levels. Some of these parts might require the performance of actions such as grasping parts operating with grippers (as common in industry), while other operations can require auxiliary devices such as tools, ropes or levers, to be handled by the robot gripper to interact with the environment.

Consequently, the problem to be solved is to operate with enough precision so as to be able to deal with the concrete task using the adequate tools or auxiliary devices.

Knowing that the visibility can be poor when operating in unstructured and "natural environments", thus reducing the human operator visual feedback, the correction functions are generated to compensate this operating limitations.

The control architecture of this assisted teleoperation system is shown in fig. 3. This schema shows that through the processed visual information, based on the scene singular points, an additional feedback loop corrects precisely the position roughly provided by the human operator.

Consequently, the position set point to be sent to the telemanipulated arm will result from the following expression:

$$X_c = a\,X^*_v + (1-a)\,X_e \qquad (1)$$

Conceptually, X_e correspond to the position orders given by the human operator, through, for instance, an

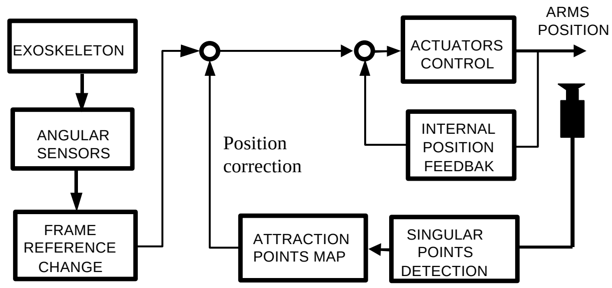


Fig. 3 Control architecture

exoskeleton, and X_v is the position computed by the vision system, corresponding to the detected target point. The coeficient α determines the weight with which the automatic and the manual components affect the final value.

Although conceptually we add the weighted position values to compute each new position set point, the effective computing of this data is done through the topological transform of the operating space. This α becomes a function that varies according to the working conditions.

5. 1 The topological transform function

Following the transformation criterion described in section 3, the teleoperated arm, the slave, works in the transformed space according to the orders received from the operation in the Euclidean, or uniform space. This fact presents the drawback that the transform equations must be computed within the dynamics of the system, increasing the computing complexity. Thus, it is convenient to change, that is, work in the transformed space from the point of view of the human operator and to keep the Euclidean space in the slave dynamics. Thus, we will use the inverse transform, that is the space will expand in the area close to the origin and will contract further away.

We must look for a transform function that applied to every point of the space returns a new function resulting from expanding or contracting this space according to the distance to the point of interest.

Let's assume that x is the value, a position in the Euclidean space, that we want to transform and f(x) is the function that applied to x, returns its transfrom x*. Now, we will search a function g(x) that added to x gives the required f(x).

Defining, for simplicity, the origin of the coordinates frame as the position of the target, when the end-effector is far from the point of interest we will have that x* = x. The space contracts when the arm approaches the origin, that is,

$$0 > \frac{dg(x)}{dx} > -1 \qquad \text{for} \qquad 0 < |x| < b \quad (2)$$

being b the distance to the origin where the topological transformation is applied. Again, closer to the origin, the space will expand significantly, and

$$\frac{dg(x)}{dx} >> 1 \qquad \text{for} \qquad 0 < |x| < a \qquad (3)$$

being a the distance to the origin that defines the expanding area. Fig. 4 shows a continuous function based on this criterion. In this case the function is:

$$g(x) = \frac{4x}{1+x^2} \qquad (4)$$

$$f(x) = g(x) + x = \frac{4x}{1+x^2} + x \qquad (5)$$

The function g(x) has a positive first derivative for values of a = 0,4. This derivative decreases, with a negative value until ∞. Nevertheless, when x approaches the value b, the derivative approaches zero. The deformation resulting from applying this transform is shown in fig. 5. In this image it can be observed that the angles do not maintain themselves constant in the intersections of the coordinates. Nevertheless, this problem can be solved using polar coordinates to compute the transform, and afterwards change again to Cartesian coordinates. This way, we get an isotropic transform. Using other coordinates bases, such as elliptical, other deformations that fit better with the requirements of the robot operation can be obtained. We can relate different deformations to the different objects or tasks, to adapt better to the task requirements.

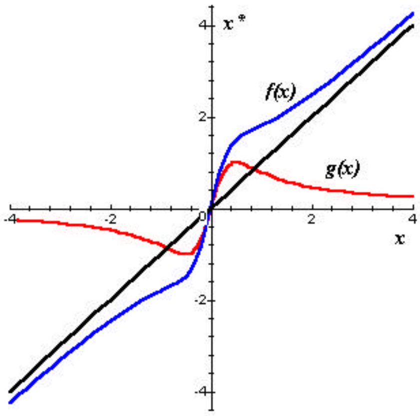


Fig. 4 Topological transform function

Thus, once the transformation function is obtained, it must be applied to the object of interest in such a way that the operation space will be deformed in a degree that depends on the distance to the element of interest in the scene.

Therefore, the orders applied to the slave will be those resulting from equation (1), but now considering X_c as the set points of the robot arm in the Euclidean space, X_v* the coordinates obtained by means of the spatial transformation form the information produced by the stereoscopic vision, and X_e the coordinates of the exoskeleton. We must consider that:

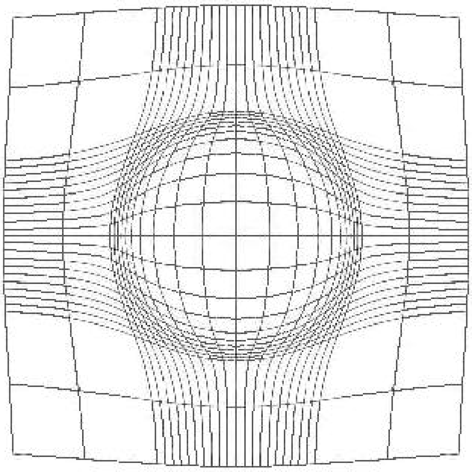


Fig. 5 Space deformation using a continuous topological transform

$$X_v^* = f(X_v) \quad \text{and} \quad a = k\, d$$

being f the transformation function applied to the position of the target from the point of view of the observer or of the end-effector seen through the position X_v obtained from the vision system. d is the Euclidean distance between the position X_v and the object of interest (that we have taken as origin of the coordinates frame), and k is a normalisation constant.

5. RESULTS

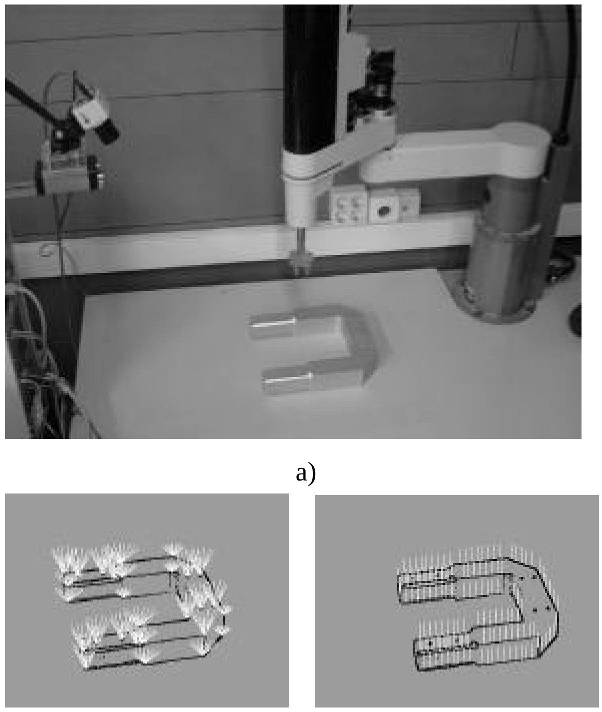
This method, that has been tested in a laboratory scenario, has resulted to be highly efficient in telemanipulation tasks. The laboratory scenario has enabled us to define the position correction function in applications such as insertion, or machining operations, fig.6, even when the parts are in movement.

The improvement on the operation dexterity has been achieved by associating the correction function to attract the arms, to the scene elements to be manipulated. The potential wells are computed from the relevant segments of these objects, such as holes or end of prominent areas.

6. CONCLUSIONS AND FURTHER WORK

The goal of this work is to compensate the low dexterity of a human operator, mainly due to the lack of tridimensional visual information. Thus, some intelligence is provided through the computing of the adequate correction function according to the objects to be manipulated, or the objects in the environment.

This work is part of the research going on in the group in the field of assisted teleoperation. In this context, the next steps are the integration of the different assistive subsystems to build a friendly human-robot interface



a)

b) c)

Fig. 6 Laboratory scenario for assisted manipulation using an Scara arm. a) The scenario, b) attraction geometrical space for high curvature lines, c) attraction geometrical space for low curvature lines

including the interaction by means of gestures, as a natural language Amat et al. (2001) or the availability of augmented reality images, to get a good enough environment feedback.

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