New Architecture of Semiautonomous Teleoperation for Obstacle Avoidance

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***Abstract*—Teleoperation is used to extend human manipulation skills over an arbitrary distance and an arbitrary scale. In order to enhance this endeavor, the semiautonomous teleoperation bets on sharing the control between the operator and the computer programmed with algorithms. The inclusion of such algorithms in the teleoperation systems has created a multiple types of architectures and in this work is proposed a new architecture for semiautonomous teleoperation by using information from objects or obstacles in the remote location. Results given in this study are obtained by an algorithm for obstacle avoidance. This algorithm represents the autonomous decision-maker in real-time, while the operator remains in control of tasks unsolvable for machines. Here is shown that not only the time is saved but computational resources are also minimized and that safety of the cohabitation with robots is more possible.**

***Index Terms*—semiautonomous teleoperation, new architecture, algorithm for obstacle avoidance, feedback from remote location ́s objects**

I. Introduction

In the past few decades, scientific community has worked on provide the teleoperated systems more stability because of the time delays [1]-[7], the interest in solve this and other problems is that the teleoperation permits to human being to handle robots from in an arbitrary distance, and human's ability to operate in an otherwise inaccessible place. As a result, teleoperation is a cost-effective way to work in remote locations, often hazardous [8]. The literature investigation has shown that there are some computational architectures that enhance the teleoperation systems with autonomous capabilities and they are named as semiautonomous teleoperation [1], [8]-[16]. Nevertheless, there is a lack of reports about semiautonomous architectures that includes information provided from the objects *per se*, such as position, and here we designed an innovative architecture of semiautonomous teleoperation which considers inputs from the remote location’s surroundings directly to the computerized controller of the teleoperated robot.

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II. Background

A. Related Work about Teleoperated Systems

Teleoperation is the extension of human senses and its manipulation skills to a remote location through artificial sensors and actuators [17], [18]. Usually, teleoperation is classified in two groups [17], [19], [20]: in the first group are those systems with any kind of autonomy e.g. Direct Teleoperation [21], [22]. In the second group are the semiautonomous teleoperated systems, e.g. Shared or traded teleoperation systems [8], [23], [24] and the supervised control systems [6], [25], [26]. One example for teleoperated systems with a semiautonomous reaction to obstacles is found in [27] where the authors occupied a haptic device to advert to the user about the presence of an obstacle through *force feedback*. In general, semiautonomous teleoperated systems are compose with two parts, the first is the human controlled situations (non-autonomous component) and the second is the autonomous component that makes decisions on its own. Yet another property in the non-autonomous component is that the information from the surroundings in the remote location necessarily has to be perceived by the operator in order to take a decision, so we demonstrate here that is possible to solve problems with information provided by the objects. Finally we have noticed that a way of demonstrate semiautonomous behavior of the system the most common task is to avoid an obstacle [25]-[27], that is why in this work we will apply a geometrical avoidance algorithm generated an example of the semiautonomous teleoperation to perform as the autonomous component, during a *pick and place* task.

B. Properties of the Semiautonomous Teleoperation

The most relevant features of the semiautonomous teleoperation are enumerated as follows:

1) The participation of a human is always involved in order to take decisions which the machine still cannot do.

2) The manager of the teleoperated robot is traded between the man and the machine as the situations come along, form example: time delays, obstacles, among others.

3) The artificial control (autonomous component) assists the operator during the task and protects the robot from damage.

4) The artificial control is embodied in programs constituted mainly on independent algorithms which interact with each other in a synergistic manner.

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III. Semiautonomous Teleoperation Architecture

A. Explanation of the Architecture Novelty

The Semiautonomous Teleoperation Architecture is shown in the Fig. 1, where the main components are considered such as the operator, the communication channel, the robot and the controller. Also is seen the relation between the elements, which is the flux of information. But the main difference in this architecture is that the objects are provided with an internal system capable of *emanate* information such as its position, orientation, geometry, weight, among other usable data.

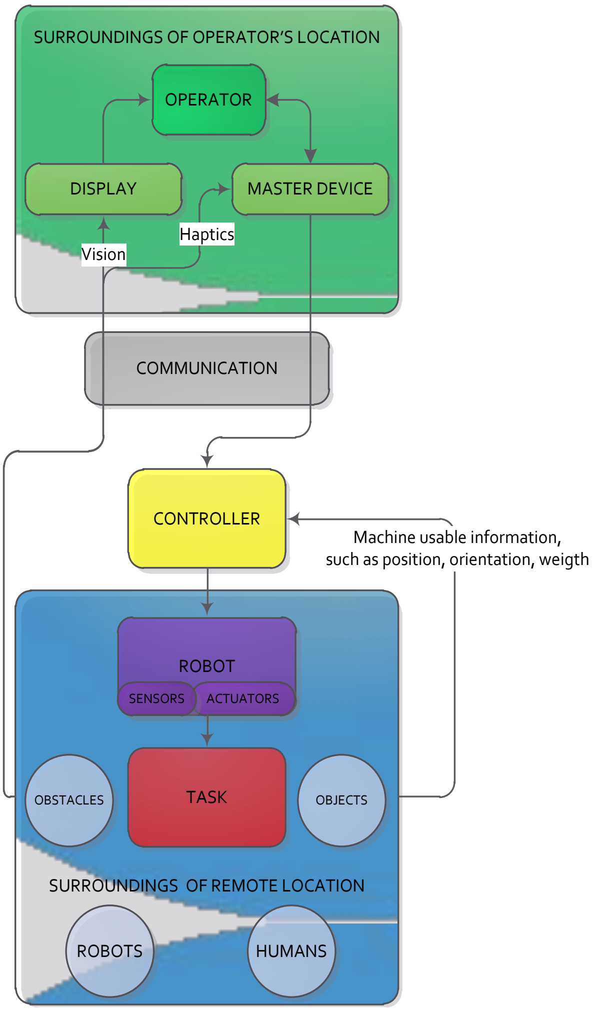

Figure 1. The new semiautonomous teleoperation architecture

In the next section, we want to demonstrate the operating principle of a very particular teleoperation system, taking into consideration only a direct teleoperation with an obstacle avoidance algorithm. The main goal is to simplify the processing of the avoidance without any other kind of feedback.

B. The Obstacle Avoidance

An obstacle is a physical barrier that avoids the coexistence with other bodies in a same space. The response towards an obstacle is the setting up of a distance, between the obstacle and the moving device, to avoid collisions and damages (see Fig. 2).

The shape we conceive to aid the avoidance is a SPHERE enveloping the obstacle as represented in Fig. 2.

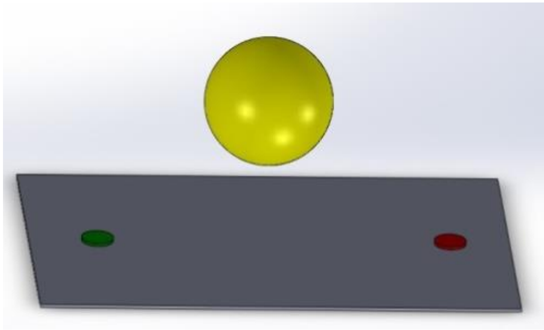

Figure 2. Representation of the obstacle surrounded by a SPHERE in yellow.

Evasion algorithm synthesis. We propose to generate a distance in every direction between a given point A (xa, ya, za) (that represents the robot's end-effector) and an object (the obstacle) located in a point coincident with its center, that we have label as O (xo, yo, zo), and finally this object is enveloped within a sphere with a known radius R. See Fig. 3 for a representation of the algorithm representation.

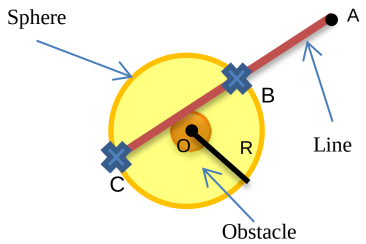

Figure 3. Seting the elements for the algorithm evasion solution

Given the equation of sphere:

$$(x - xo)^2 + (y - yo)^2 + (z - zo)^2 = R^2 \qquad (1)$$

And the equation of the straight line defined between two points:

$$\frac{x-x1}{x2-x1} = \frac{y-y1}{y2-y1} = \frac{z-z1}{z2-z1} \qquad (2)$$

where we take the Point 1 as the center of the sphere $(x1 = xo,\ y1 = yo, z1 = zo)$ and the Point 2 $(x2, y2, z2)$ as the reference that the robot must follow, and we called Point A (xa, ya, za), for the purposes of the algorithm, resulting in $x2 = xa,\ y2 = xa$ and $z2 = za$ NOTE: the algorithm is executed only if the distance between Point A and Point O is minor to the radius R of the sphere.

Solving the equation system formed with 1 and 2, and the conditions mentioned above, there are found two possible solutions: points B and C as follows:

$$xb, c = xo \pm R * rootxyz * (xa - xo) \qquad (3)$$

$$yb, c = yo \pm R * rootxyz * (ya - yo) \qquad (4)$$

$$zb, c = zo \pm R * rootxyz * (za - zo) \qquad (5)$$

where:

$$rootxyz = \sqrt{1/[(xo - xa)^2 + (yo - ya)^2 + (zo - za)^2]} \quad (6)$$

In order to choose only one point, we calculate the distances between the points A to B ($\overline{AB}$) and A to C ($\overline{AC}$), then we compare which distance is smaller: for example, B is chosen if $\overline{AB}$ is minor to $\overline{AC}$.

IV. Experimentation with the Algorithms on the Teleoperated System

The conducted experiments use a system Master-Slave for teleoperation shown in Fig. 4. A person at the local workstation (Fig. 4a) interacts with a master device (Fig. 4b) and with a visual interface (Fig. 4c). The information of position (x, y, z) is sent through the computer to a virtual robot displayed on the screen. The only feedback for the operator is the above mentioned screen virtual representation of the robot.

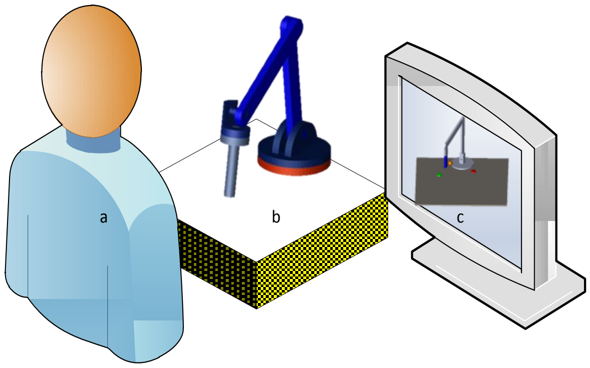

Figure 4. Teleoperated system, a) operator, b) master device at local workstation, c) Visual Interface displaying slave device at the remote location. See appendix for engineering and mathematical details.

In the local environment, the operator was sited facing the master device, holding the final link with one hand.

In the remote environment, there were a set of two points: the initial and the final, both had to be in the reach of the slave device.

Before initialize the test, the researcher’s instruction to the operator was to place the robot’s end effector from the initial point to the final point. The only feedback to the operator was a 2D screen (see Fig. 5). The operator had no control over the camera ́s perspective. Finally, a moving obstacle was inserted on the remote location virtually with an arbitrary trajectory.

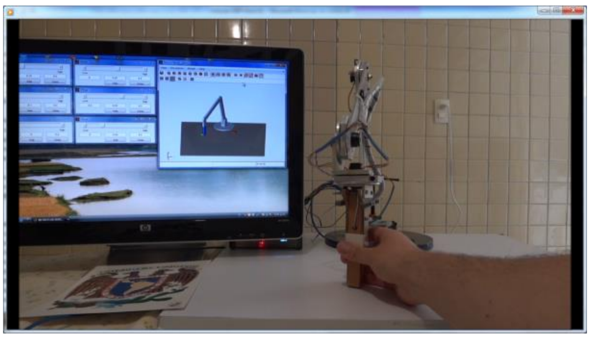

Figure 5. Experiment location view.

All the data from the operator’s master device and the robot’s end effector was measured in Cartesian position vectors (x,y,z).

A. Results

Below are presented the results teleoperated transfer task with the moving obstacle. See figures from de Fig. 6 through the Fig. 10.

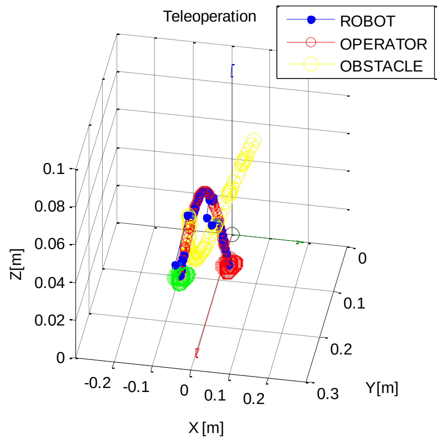

Figure 6. An overview of the results

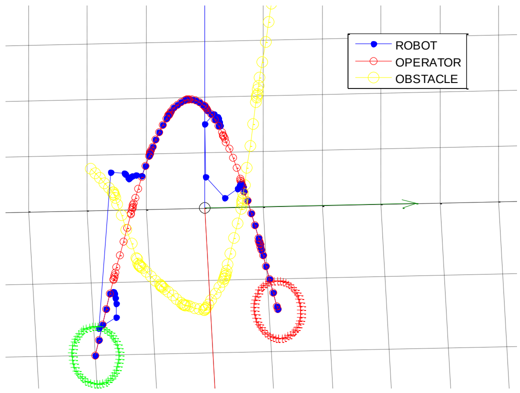

Figure 7. A close up of the trajectory of the robot, the operator and the obstacle, the obstacle deforms the robot’s trajectory.

We added the results seen on each Cartesian axis, where is noticed that the obstacle deformed the original trajectory made by the operator.

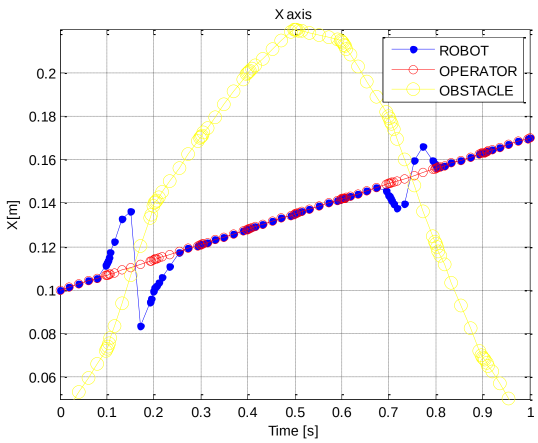

Figure 8. Behavior in the x axis

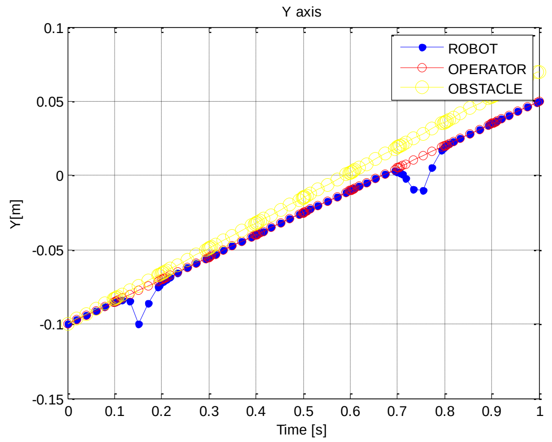

Figure 9. Behavior in the y axis

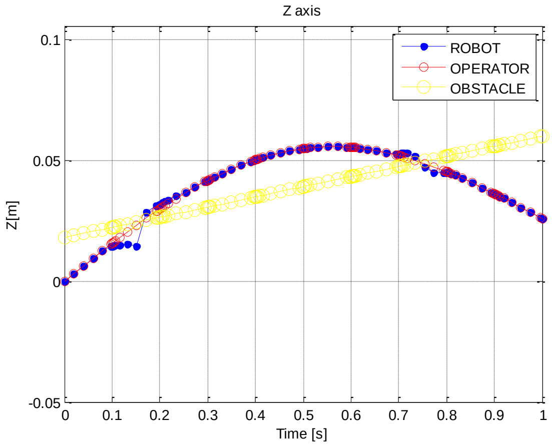

Figure 10. Behavior in the z axis

V. Discussion

In the figures are described two trajectories, one for the Operator (master) and one for the Robot (slave), normally the robot follows the operator, with the exception when an obstacle gets closer to the robot's end effector. The obstacle's trajectory is arbitrary, in this study, is simulated with a sequence of Cartesian coordinates that goes through operator ́s trajectory (and with the robot's) in two particular points. The feedback for the programmed algorithm is given by the obstacle ́s position. The algorithm actively deforms the robot's trajectory without alter the operator ́s trajectory. The instructions for the algorithm are merely arithmetic and the only condition for this to happen is that the robot's end effector is near to a given distance from the obstacle. The outputs of the algorithm are new coordinates of robot's trajectory meanwhile the speed remains in the control of the operator.

VI. Conclusions

In this work, we demonstrate a new semiautonomous teleoperation architecture and we synthetize an algorithm in order to make an example that help us to demonstrate that is possible to use information acquired directly from the objects in the remote surroundings. In this case was for obstacle avoidance, but can be useful for other semiautonomous behaviors considering that recently, the information of things can be uploaded to the cloud and used to perform control actions in robots, e.g. using the new technologies of Internet of things (IoT).

Furthermore, the participation of the avoidance algorithm during the motion modifies the trajectory of the transfer task without the participation of the operator's will in real time, i.e. human attention is not needed for avoidance, relieving the operator from over-think every action required.

We found that advantages are mainly two: first, the feedback is reduced to minimum, i.e. operator controls the slave manipulator with only a bi-dimensional monitor and the master device has no actuators for operator's force feedback as needed in bilateral teleoperation (see [27]) which is an advantage in order to avoid the use of complicated force-feedback or haptical instrumentation, and second, the amount of instructions to process the algorithms are low, also they are not complex or ambiguous, and they do not require a powerful processor (see [8]), even a microcontroller can support the equations of our algorithm.

In the future we have foreseen the existence of complete autonomous systems that exploit the model provided here. Furthermore, the architecture and the algorithm can be extrapolated to unmanned aerial vehicles, such as drones that carries a positioning system and communication between multiple drones. Also is recommended to do research about orientation and grasping objects with robots.

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