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5 DOF Instrumented Master Device For Experimental Understanding Of Intuitive Teleoperation

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Abstract

Teleoperation it is a modern challenge within the areas of mechatronics, e.g. precision mechanics, control electronics, computational algorithms. Teleoperation arose from the necessity of handling nuclear material, but in recent years has come essential in others activities such as the space or undersea exploration, mobile robotics, medical applications and entertainment. The main goal in this work is to study the "operation at a distance," with a master-slave system, to define the concept of "Intuitive Teleoperation," like a novel approach to perform semiautonomous teleoperation, based on incomplete information from the environment, objects and system. In this level of the investigation the experimentation was realized with a 5 DOF anthropomorphic device (master device) that acquired data of the movements from a human operator, which was sent to a 5 DOF anthropomorphic robot (slave device). Both, direct kinematics (over the master device) and inverse kinematics (over the slave device) were used to calculate their space parameters (point coordinates, orientation) and to implement intuitive algorithms. Has been observed that the master device movements are followed and enhanced by the slave subsystem when the intuitive algorithms are activated. Semiautonomous teleoperation was achieved using a 5 DOF instrumented master device. The experiments enhanced the "operation at a distance" by defining an intuitive algorithm.

INTRODUCTION

Teleoperation is to perform some kind of action at a distant location. A mechatronic system is suitable for experimental research in this branch of robotics. During teleoperation, a human interacts with a remote workstation and generates control modes of teleoperation starting with "manual control" to "supervisory control[1]" and "fully automatic control," to understand details see Sheridan (1989b). According to the author the differences lies on where the decisions are made, sometimes only by the human, sometimes only by the computer or in other cases the control is shared. When the architecture allows participation of both the human and the computer we call this a ***Semiautonomous Teleoperation***.

In teleoperation is possible to find obstructions such as objects that prevent the trajectory generated by operator, this is when Semiautonomous Teleoperation come along. It will be seen in next paragraphs that other researchers has made approximations towards *agents* that simulated a kind of artificial intelligence. Introducing, an agent with reactive algorithm performs an action with the available data in the instant while the deliberative agent requires choose an action from a set of previously loaded behaviors.

Brooks (1986) introduced a technique called *subsumption* architecture that decomposes complicated intelligent behavior into many "simple" behavior modules, which are in turn organized into layers.

Arkin (1987a) used a behavior based technique to perform autonomous navigation of robots. This scheme combines simple behaviors in order to produce coherent action for the robot.

An approach of semiautonomous control related to robotic arms is written by Kathib presenting a real-time obstacle avoidance approach for manipulators and mobile robots based on the "artificial potential field" concept [Khatib (1985)].

Albus, McCain et al. (1989) defined the *NASA/NBS Standard Reference Model for Telerobot Control System Architecture* (NASREM) is where are written the functional requirements and specifications of a high level system of robotical control for flight assistance in a space station of NASA (National Aeronautics and Space Administration). The NASREM integrates artificial intelligence concepts such as decomposition, hierarchical planning, and expert systems among others. Also includes multivariable state space control, reference model

[1] Computer Aided Teleoperation

adaptive control, dynamic optimization and learning systems in order to perform a better teleoperation.

Stein and Paul (1994) programmed a supervisory control approach to remote manipulation. They made a behavior-based controller constructed under the principles of the subsumption architecture of Brooks, in order to fulfill the need for "semi-autonomy" at the remote site prescribed by supervisory control. This work presented an interface that allowed operator interaction with the behavior-based controller, which provide diagnostic and kinesthetic state information to the operator during teleoperation.

Stoytchev and Arkin (2001) explained a robot architecture that holds three inherent challenges to work among humans: 1) how to operate at dynamic and unpredictable environment, 2) how to deal with high level human commands, 3) how to be friendly to human users. This researcher's architecture combines three components: deliberative planning, reactive control and a "motivational" element.

García, Carelli et al. (2003) developed for a robotic teleoperation system with communication time delay, considering the hybrid systems theory. Their definitions are closely linked to some values of the trajectory of the remote robot end-effector. The proposed control structure gave "autonomy" to the remote station, especially when a communication interruption aroused.

Yoon (2004) proposed a mixed force and motion command-based space robot teleoperation system to solve the communication time delay in the space robot teleoperation, moreover, they have also developed a compact 6-degree-of-freedom haptic interface as a master device, in order to use two methods, which are a 'master–slave' approach and a 'force-joystick' approach. Additionally they saw that the 'master–slave' approach is the best control method for contact tasks in which the directions of motion of the slave arm and of the operator's input force are different, as in the surface-tracking task.

One of the fundamental and critical research areas in autonomous mobile robotics is navigation, which generally includes local navigation and global navigation. The first, often called reactive control, learns or plans the local paths using the current sensory inputs without prior complete knowledge of the environment. The second, often called deliberate control, learns or plans the global paths based on a relatively abstract and complete knowledge about the environment. For our purposes combining two or more types of control, there is a word to describe this situation: ***hybrid.*** Chunlin worked with Hibrid control architecture via combining reactive and deliberate control using a particular algorithm that come [Chunlin, Han-Xiong et al. (2008)].

Recently intelligent functions and algorithms have been proposed for computer assisted teleoperation, such as Calinon, Evrard et al. (2009) investigation that recognizes the user's intention in order to ensure appropriate assistance. Calinon use a statistical approach using haptic information such as position, speed and strength, to determine what the operator wants to do, so that the slave system (robot) learn tasks and to assist them during the teleoperation.

Continuing the work of Calinon, Stefanov, Peer et al. (2010) experimented with a system that trains teleoperated robot before introduce it to the workspace, also uses a probabilistic algorithm, but draws **fragments** of events (classified by similar characteristics) to make something similar to a database and use them during the execution of tasks by the robot, making it quick and precise during the different stages of the teleoperation.

Since other researchers have made an approach to hybrid supervisory control, our premise about semiautonomous teleoperation is to introduce an algorithm into the robot frame for "decision-making" during the operation. Psychology studies intuition taking into account the nature and mechanisms of the human decision-making. Robotics indicate that decision-making is not, or at least not only, an intellectual task, but also a process of dynamic behavioral control, mediated by embodied and situated sensorimotor interaction [Hardy-Vallée (2010)].

Our experimentation is based on the fact that some characteristics of human intuition can be simulated in a machine fashion. A later section gives details about intuition for this work.

Our purpose in this paper is to identify those characteristics of human intuition that can be simulated by a robot through experimenting with a teleoperated master-slave system.

Within the decades, Teleoperation has been object of study because of its applications, but for science has come to be a challenge to generate new perspectives to solve its problems.

INTUITIVE PROCESS

Intuition is a concept drawn from epistemology to describe knowledge which is direct and immediate, without intervention of the deduction or reasoning, being usually self-evident [Ferrater-Mora (1984)].

In philosophy, intuition has been studied, among others, by Descartes and Kant. The first, from pure rationalism, attributes the meaning of immediate knowledge. The second distinguishes that there is a sensible intuition and intellectual intuition.

According to some psychological theories, it is called intuition to knowledge that does not follow a rational way for construction and formulating, and therefore can not be explained or even verbalized. The individual can relate such knowledge or information to previous experiences, but usually are unable to explain why they reach a certain conclusion. Intuitions often occur more frequently as sudden emotional reactions to certain events or sensations and elaborated abstract thoughts [Morris and Maisto (2009)].

Another proposal of definition of Intuition from Harteis, Koch et al. (2008) usually is defined as the *capability to act or decide appropriately without deliberately and consciously balancing alternatives, without following a certain rule or routine, and possibly without awareness*. It allows action which is quick (e.g. reaction to a challenging situation) and surprising, in the sense that it is extraordinary in performance level or shape.

We suggest that **intuition** is a rapid understanding of the situation which usually leads to a sudden finding of a solution.

Fernand Gobet and Philippe Chassy, (2009) analyzed the work of Hubert Dreyfus who argued that intuition is result of a cerebral and mental holistic processing [Dreyfus and Dreyfus (1988)]. In the opposite, they analyzed the proposal of Herbert Simon which states that simple mechanisms based on pattern recognizing are enough to explain intuition. Simon call this patterns *Chunks* and *Templates*, which the human recognize in order to made decisions [Chase and Simon (1973)]. Nevertheless, Dreyfus and Simon share opinions about intuition: its rapidity, fluidity and the fact that it requires lots of practice and experience. Gobet and Chassy conclude that can not be taken separately both theories, because intuition is an integrative process as mentioned by Dreyfus, but the mechanisms that generates it are all the set of information pieces, as mentioned by Simon Gobet and Chassy (2009). In the same year, Seligman enumerates the characteristics of a intuitive process which are: a) rapid, b) not conscious, c) used for decisions involving multiple dimensions, d) based on vast stores of prior experiences, e) characteristic of experts, f) not easily or accurately articulated afterwards, and g) often made with high confidence. However, Seligman states that cognitive architecture of human intuition is essentially a mystery [Seligman and Kahana (2009)].

According to Hogarth (2001) argues that intuition can be educated based on five main ideas. 1) In a single organism much of the information processing is carried out in automatic ways without the organism's conscious control. 2) These systems of processing information have evolved over time in layers that represent a line of adaptation to environmental demand. 3) Many processing systems are automatic. Through practice some processes can become automatic, however not all automatic processes are intuitive. 4) Learning is shaped by experience. 5) There are two systems for learning and doing: a) The tacit system is composed of all processes that occur automatically and includes intuition. b) The deliberate system includes all processes that require attention and deliberation, like analysis, logic, and synthesis. The two systems can work together to produce leaning or action.

Two set of mechanisms are identify from research, not only in robotics but in psychology as well, the making plans or **deliberative agent** and an automatic or **reactive agent**, we are dividing them in blocks to generate the Architecture of a *Intuitive Teleoperation* seen in Figure 1 defining each functional block are defined as listed below.

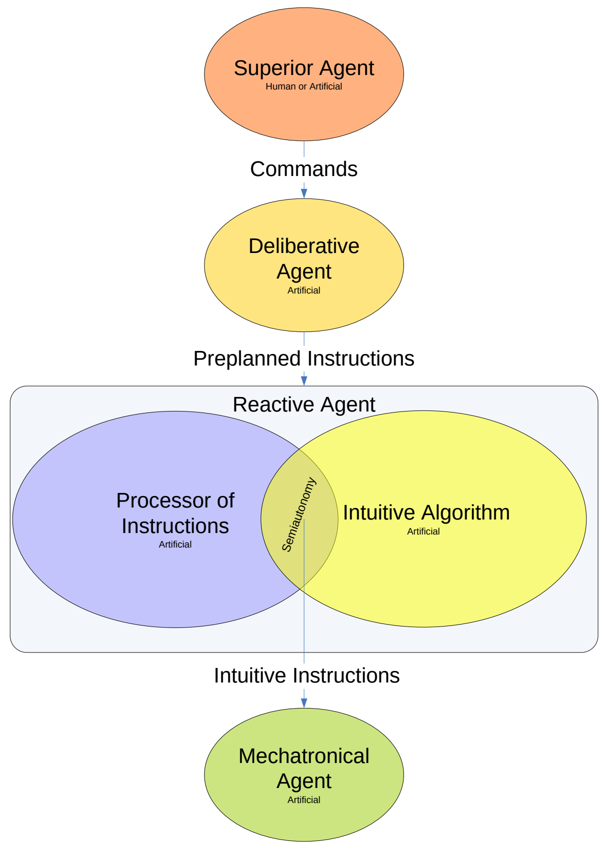

Figure 1. Architecture of *Intuitive Teleoperation.* Flux of information during the operation at a distance

i. Superior Agent. States that a human is the beginning of instructions of movement, where all its intelligence is used during teleoperation. Nevertheless, there is a possibility of having a intelligent or expert machine "superior" to the Slave System
ii. Commands. The joint between blocks are the teleoperator movements detected by a Master System
iii. Deliberative Agent. This is the making plans block according to the information previously acquired.
iv. Preplanned instructions. These are the plans made by previous algorithm.
v. Reactive Agent. This is where the intuition comes along unifying the instructions from the teleoperator already improved by intermediary blocks.

vi. Semiautonomy. The joint between the Processor of Instructions and the Intuitive Algorithm, providing the system two possible master pathways.
vii. Intuitive instructions. These are the intuitive characteristics that are extracted into a machine or in our case a Mechatronic System
viii. Mechatronical Agent. Constituted Slave System designed through the synergistic integration of mechanical engineering, with electronics and intelligent computer control.

The goal of machine intuitiveness is to give machines the ability of: a) represent knowledge appropriately, b) use the knowledge of the environment and circumstances, c) draw conclusions or decisions from incomplete pieces of information or knowledge, and d) perform actions to solve complex problems in the real world. The Intuition has an uncertainty factor but avoids logic or reason to perform.

In the next section we propose an algorithm for the intuitive response during teleoperation.

METHODOLOGY FOR EXPERIMENTATION

Our objective is to observe how to reproduce an action by introducing an algorithm that simulates intuitiveness in machines.

The goal of the experiment is to insert reference position in space through a master device instrumented and replicate them in a virtual system, with a certain adjustment by introducing an intuitive algorithm.

Initial hypothesis of the experiment is: During the teleoperation is possible to introduce an algorithm that simulates intuition in machines, quick action may reach the slave system, despite not having "enough" feedback.

Design and Implementation of the experiment.

It has a data acquisition system of 5 degrees of freedom (DOF) from the operator which send data to the robot for execution. This system will be called "Master." Input data.

It has a robotic system with 5 DOF. This is the system known as "Slave". Output data. The outputs will be affected by the intuitive algorithm.

Experiment data are evaluated are the position of the slave system in relation to the references of the master system (operator).

The master system is a 5 (DOF) anthropomorphic device instrumented with incremental optical encoders on each joint. With the angles is calculated the direct kinematics using Denavit Hartenberg's Method [Wen-Tsai (1999)].

Table 1. D-H Parameters of a 5 DOF Device

Joint	αi	θi	a	d
1	-90	$\theta 1$	0	d1
2	0	$\theta 2$	a2	0
3	0	$\theta 3$	a3	0
4	-90	$\theta 4$	0	0
5	0	$\theta 5$	0	d5

The analyses require kinematic representation for the point Q, the axis on every joint and link, is why the Figure 2 shows 5 DOF device representation.

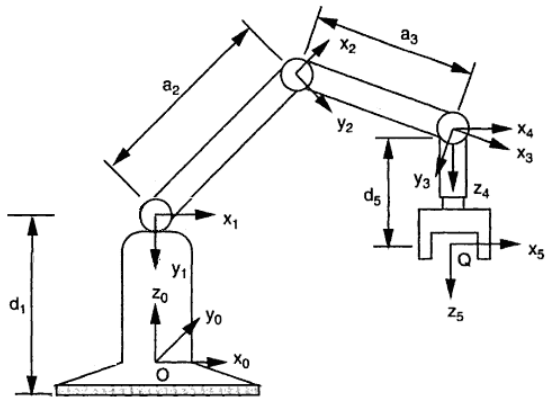

Figure 2. Schematic of the axis decomposition for the 5 DOF device analysis.

Cartesian Coordinates are obtained as follows:

qx $= a2C\theta 1C\theta 2 + a3C(\theta 2+\theta 3)C\theta 1 - d5S(\theta 2+\theta 3+\theta 4)C\theta 1$

qy= $a2S\theta 1C\theta 2 + a3C(\theta 2+\theta 3)S\theta 1 - d5S(\theta 2+\theta 3+\theta 4)S\theta 1$

qz= $d1 - a2S\theta 2 - a3S(\theta 2+\theta 3) - d5C(\theta 2+\theta 3+\theta 4)$

Orientation is composed by Pitch and Roll angles.

The Figure 3 draws the 5 DOF device and its dimensions

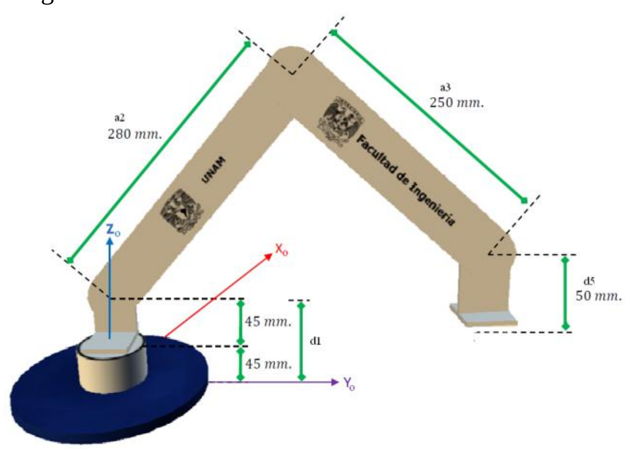

Figure 3. Master 5 DOF device seen in a virtual model

In this work, the master device depicted a follows in the real hardware, was design for the purpose of acquired movement produced by a human operator, observe that no force feedback is provide.

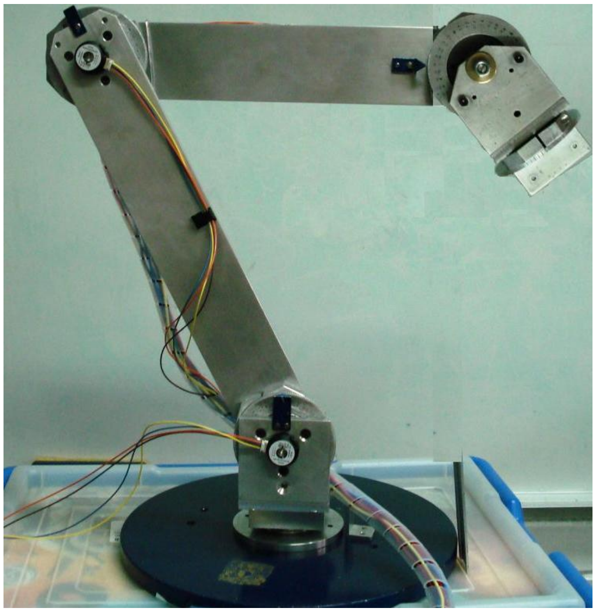

Figure 4. Photograph from the real 5 DOF device

In order to acquire the angular data towards personal computer, is implemented an electronic system composed by one main and three secondary microprocessors communicated by I2C protocol. The main processor (ATmega1280) communicates with the computer through serial communication protocol, while the secondary reads the encoders directly. The information submitted is transformed into x, y, z along $Pitch$ and $Roll$ of the Point Q (seen in Figure 2), which is the **input** parameters for the experimentation.

The Slave system is a virtual model of the Real SCORBOT 4u Robot implemented in the computer in order to simulate the real robot in its kinematical response. It was programmed the inverse kinematics that receives the information of the Point Q and calculates its own angles to reproduce as a direct teleoperation does. In Figure 5 is pictured the Slave Robot.

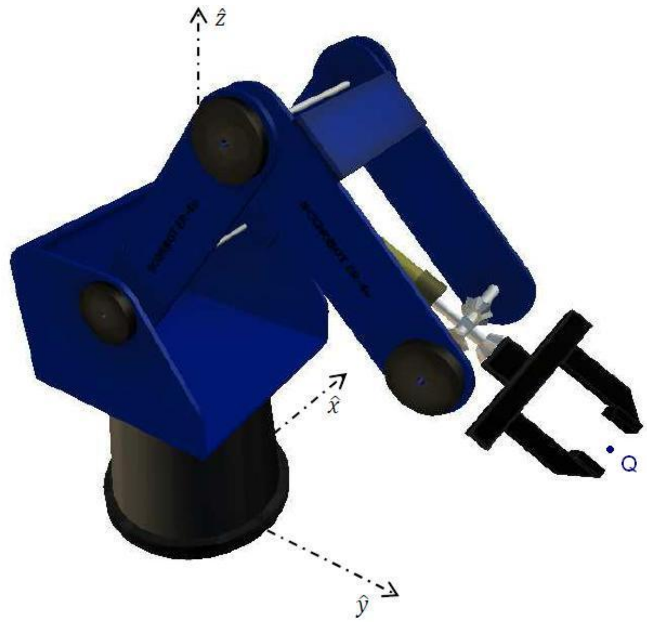

Figure 5. Virtual model of SCORBOT with 5 DOF

In this stage of the research the algorithm proposed in order to resemble intuitiveness is to include an obstacle within the workspace and geometrically produce a rapid response in the master device. This include to calculate distance between the master coordinates and the center of the object and calculate another path if the object is approaching, considering that there is no feedback, only some fragments of information such as the location of object and its radius.

In the next grid it is shown a object introduced virtually into the workspace, its center is located in Point O (0.222 [m], 0 [m], 0.336 [m]), with a diameter of 0.03 [m]

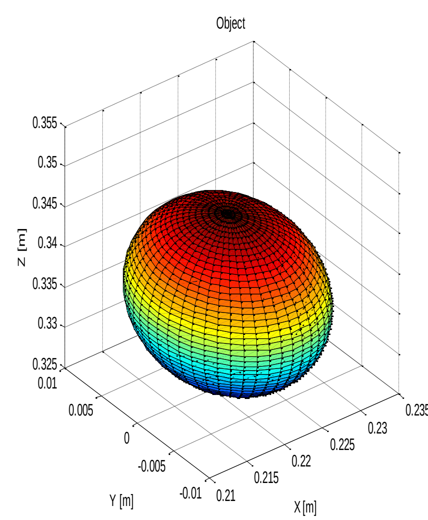

Figure 6. Spherical object.

The incomplete information is the feedback of the piece to hold or to evade by the end effector of the slave system that does not have pressure sensors or proximity to evade obstacles.

RESULTS

Previous section has shown an object which purpose is to observe the performance of the intuitive algorithm prepared for this work. The experiment consisted in moving the 5 DOF Master device by teleoperator in order to approach to the object's surroundings. Previously it was defined an affectation distance from center of object (Point O) and 5 DOF Slave device end-effector (Point Q).

In the next figures we will show results from experimentation with the Object and the Point Q of the robot.

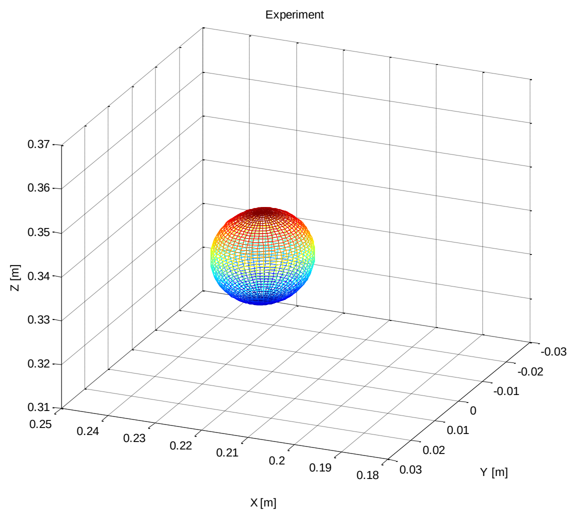

Figure 7. Object. The presence of an object is introduced to the workspace.

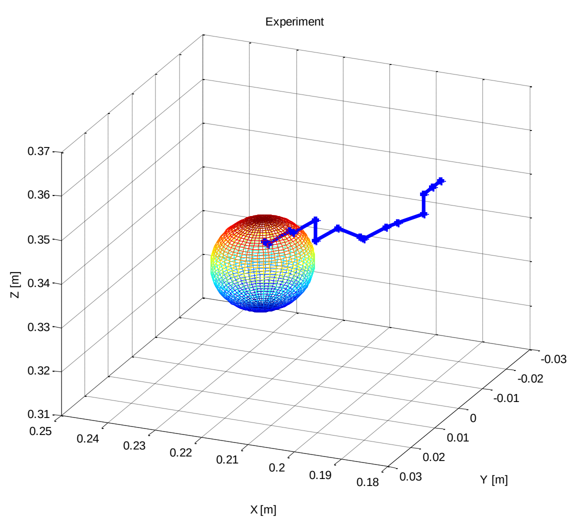

Figure 8. Non-intuitive robot. This teleoperated robot normally would go through the object. This image is an example of collision without our algorithm.

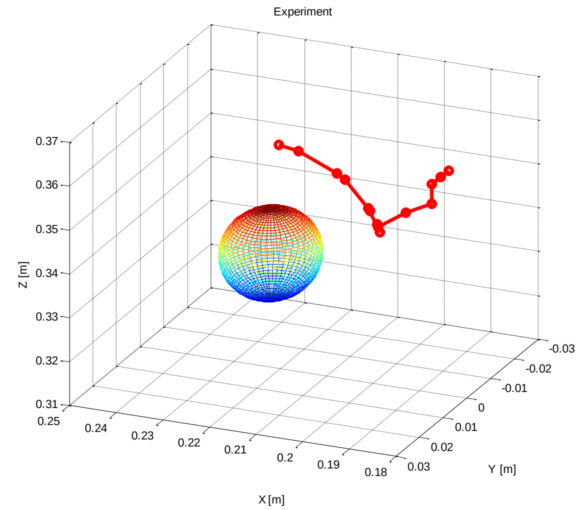

Figure 9. Intuitive robot. This teleoperated robot is using the algorithm introduced; the Point Q of the robot does not touch the object.

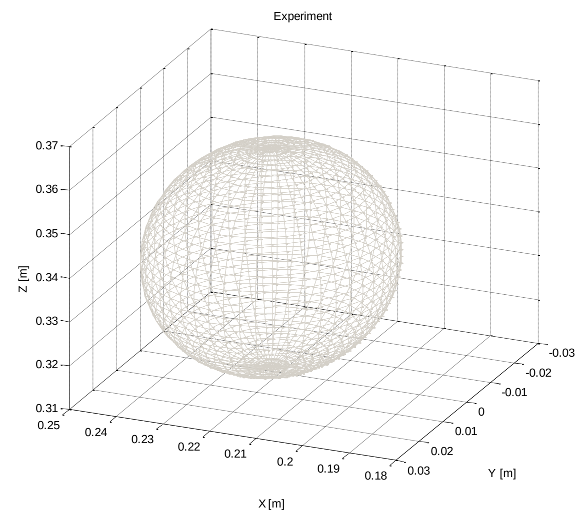

Figure 10. Intuitive Solutions Surface. The algorithm generates a field where the Point Q of the robot will not go through.

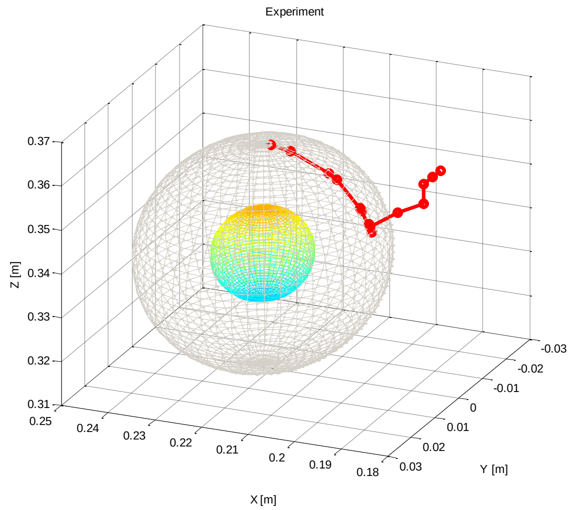

Figure 11. Object, Intuitive Solutions Surface, Trajectory of Point Q during teleoperation.

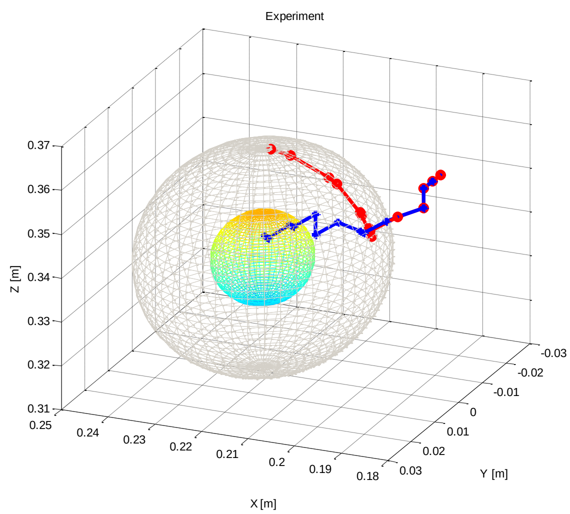

Figure 12. Combined figures of the experiment.

From Figure 12 we see in red the modified trajectory of Point Q, while in blue is seen its actual trajectory. Outer sphere represent what we call **Intuitive Solutions Surface** (ISS).

In the next Figure 13 shows the workstation where the tests were performed.

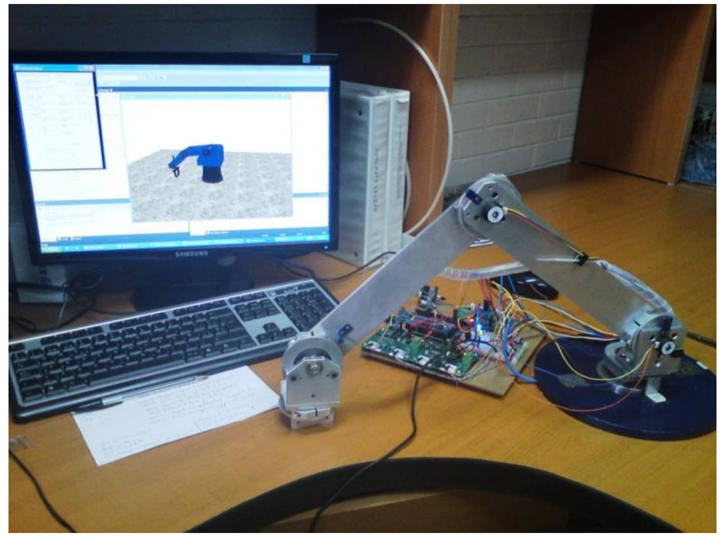

Figure 13. Teleoperation System for experimentation

CONCLUSIONS

Semiautonomous teleoperation was achieved using a 5 DOF instrumented master device. An intuitive algorithm was introduced. Geometrically it was generated a volume that we called **Intuitive Solutions Surface** were the Slave's trajectory could exist in while the Master's trajectory reside inside.
In results we saw how fast can be change Point Q location with only two parameters from an object which is not sensed by Slave system, nor the Master device. We claim that consciousness of neither the Slave System nor the "Superior Agent" was not necessary, additionally automatic and correct actions were performed. It is worth mentioning that no artificial intelligence *per se* was implemented.

Still, there are open questions about what other intuitive characteristics could be implemented considering that: 1) Consciousness remains outside intuition. 2) Lack of information could be replaced by database as memory. 3) Reactivity is the automatic actions to some events, but intuitiveness is performing automatic but correctly. 4) Intuitiveness acts putting together pieces of information (use database of workspace, tools or objects). 5) Separated algorithms could give intuitive performance.

Additionally, a Deliberative Agent (preprogrammed, preplanned before movement) may include "Robot workspace analysis" in a changing workspace, therefore one possible Intuitive teleoperation algorithm is hidden in the reachable region for the robot or analysis of workspace (reachable region for the robot) considering objects. The possibilities are enhanced when there is available information of the objects or environment from external sources such as vision or augmented reality.

In future work is considered not only obstacle evasion, but grasping objects, approximation to objects or areas with given orientation angles (Pitch, Yaw, Roll), and assembly tasks.

The need of operate robots with efficiency lead us to keep looking for those answers but more important, finding other questions.

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