Strategies for Haptic-Robotic Teleoperation in Board Games: Playing checkers with Baxter

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***Abstract*—Teleoperating robots is quite a common practice in fields such as surgery, defence or rescue. The main source of information in this kind of environments is the sense of sight. The user can see on a display what the robot is watching in real time, and maybe also a visual representation of the robot's surroundings. Our proposal involves the use of haptic devices to teleoperate a robot, Baxter, in order for the user to obtain haptic feedback together with visual information. As a proof of concept, the proposed environment is playing checkers. Our goal is to test if the inclusion of the sense of touch improves the user experience or not.**

***Index Terms*—Teleoperation, Baxter robot, haptics.**

I. INTRODUCTION

TELEOPERATING robots is quite a common practice in many fields such as surgery, defence or rescue [1]. The reason is simple: assisting a person to perform and accomplish complex or uncertain tasks in some environments may mean the difference between failure or success.

Enhancing the user experience is a key aspect in teleoperation. These systems use different interfaces (e.g. cameras, microphones or input devices) to provide sensory information to the operator, thus, improving the user experience. Traditionally, video feedback from an on-board or front-mounted camera is limited by technical constraints [2], [3] like a restricted field of view or poor resolution. In some scenarios, these constraints make it difficult for the operator to be aware of the robot's proximity to objects [4], causing a decrease in performance. To alleviate such limitations, at least partially, haptic cues (either by force or tactile feedback) have been shown to be useful in some applications [5], [6], [7], especially when the operator performs manipulation tasks [8], [9].

The motivation behind this paper is to test whether or not the sense of touch improves the user experience in teleoperation. To achieve this, we propose an experiment: teleoperate a robot to play a board game. The scenario will have two players and one game. One player is located at the game's place while the other is away, teleoperating a robot which is "physically" located at that same place. The teleoperation system consists of a Geomagic Touch haptic interface (that acts as a master device) and a Baxter robot (which acts as the slave device). The chosen board game is "checkers", a strategy game chosen because of its simplicity: all pieces are equal, except for their color, and they can only move diagonally forward. With this setup, the user experience is evaluated by defining and measuring some metrics with a group of expert evaluators.

The paper is organized as follows. Section II shows the evaluation to be performed on the manipulation strategies described in section III. The environment described in section IV is used for the experiment presented together with the results obtained in section V. Finally, the paper ends with our conclusions.

II. EVALUATION METHODOLOGY

In the following sections, the environment and the experiment will be described in detail. But first of all, the main goal of this paper will be presented. Our main goal is to test whether or not the sense of touch improves the user experience in teleoperation, a task usually commanded by sight.

For evaluation of our experiment we used the Guideline for Ergonomic Haptic Interaction Design (GEHID) developed by L. M. Muñoz, P. Ponsa, and A. Casals [12]. The guide provides an approach that relates human factors to robotics technology and is based on measures that characterize the haptic interfaces, users capabilities and the objects to manipulate. We chose this guide as it is a method that aims to cover aspects of haptic interface design and human-robot interaction in order to improve the design and use of human-robot haptic interfaces in telerobotics applications.

The method to be followed for using the GEDIH guide consists in forming a focus group composed of experts and designers in order to follow these steps for every indicator defined: analyze the indicator, measure the indicator, obtain the GEDIH global evaluation index and, finally, offer improvement recommendations in the interface design. After the GEDIH validation, a users experience test can be prepared in order to measure human-robot metrics (task effectiveness, efficiency and satisfaction) [13].

As our first step, we detailed a set of selected indicators that provide a quantitative and/or qualitative measure of the information perceived by the user from the teleoperated environment. The selected indicators are the following ones:

- **ReactionForce/Moment**, this indicator measures the variation in the force or moment perceived when making contact with an object or exerting a force over it.
- **Pressure**, in this case the variation in the force perceived under contact with a surface unit is measured.
- **Rigidity**, measures the absence of displacement perceived when a force is exerted.

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- **Weight/Inertia**, this indicator measures the resistance that is perceived by the user when an object is held statically or moved from one place to another.
- **Impulse/Collision**, in this case the indicator measures the variation of the linear momentum that happens when colliding with objects in the teleoperated environment.
- **Vibration**, this indicator measures the variation in the position perceived when an object is manipulated by the user.
- **Geometric Properties**, in this case, the perception of the size and shape of the manipulated objects in the teleoperated environment is needed.
- **Disposition**, it is also necessary to measure the perception of the position and orientation of objects.

These indicators have to be related to the basic tasks to be performed during the experiment in order to establish how to obtain specific results for each of them from the user experience.

III. MANIPULATION STRATEGIES IN BOARD GAMES

Most board games contain elements with different sizes and shapes to play: chips, dices, dice cup, pawns. When we think of a human-robot game, we have to think of two ways of playing, by using virtual and real interaction. In this research, virtual interaction is our starting point. That is, games in which a robot performs the action, but the moves are commanded by a human. We are not considering real interaction games, in which the robot takes the decisions and is able to perform the action by itself [15].

In order to detail the manipulation strategies that are going to be used in the rest of the experiment, first we will set the basic actions to be performed by the teleoperated robot. Second, we will establish the tasks involved in each of the previous actions, and the relationship between these tasks, the robot sensors, the robot actuators, the haptic device and the operator. And third, we will relate these tasks to the indicators chosen for the evaluation of the experiment.

Fist, from the point of view of the basic actions that the robot can perform, two different ways of moving the game pieces can be proposed: one is to grasp and drag the pawns/chips along the board to a target position; and the other one is to grasp and raise the piece and move it to the target position.

Second, considering just chip games, these two basic actions can be divided into the following tasks:

- Grasp and drag:
    1) Chip presence: Determine if the chip is near the manipulator jaw.
    2) Calculate start and end position: Determine the plan to move the chip to the desired position.
    3) Chip grasping. Is the task that allows the manipulator to grab an object, or to lay down the jaws on top of the chip.
    4) Chip pushing. Move a game piece by applying a force to it and move it along the board.
    5) Chip presence: Determine if the chip has reached the desired position.
    6) Chip releasing. Release the chip in the desired position.
    7) Chip presence: Determine the final chip position.
- Grasp and raise:
    1) Chip presence: Determine if the chip is near the manipulator jaw.
    2) Calculate start and end position: Determine the plan to move the chip to the desired position.
    3) Chip grasping. Is the task that allows the manipulator to grab an object.
    4) Chip raising. Move the object upwards the target place.
    5) Chip moving. Move the chip to the estimated end position.
    6) Chip releasing. Release the chip in the desired position.
    7) Chip presence: Determine final chip position.

In a virtual interaction game, tasks from 3 to 6 can be substituted by human movements. But, what happens if we want to teleoperate the robot to perform these tasks or even what happens when the six tasks are replaced by a human that teleoperates a robot? This last scenario is the one that we are going to apply in this paper. We also propose the application of haptic devices to provide more information than simple visual perception.

In this situation, we have established the following relationships between previous tasks, the robot sensors, the robot actuators, the haptic device and the operator:

1) Chip presence: Exteroception sensors
2) Chip grasping: Exteroception sensors and haptic devices
3) Chip raising/dragging: Haptic device
4) Chip moving. Exteroception sensors and haptic devices
5) Chip releasing. Exteroception sensors and haptic devices

TABLE I
BASIC TASKS AND GEHID INDICATORS.

Basic task	Indicator
Presence	Collision on 3D movement
Grasping	Rigidity on the the grasping tool
Push	Vibration on 3D movement
Translating	Weight on 3D movement
Assembling	Collision on 3D movement

The third step is to establish a clear relationship between selected indicators and basic haptic tasks. Table I shows this relationship. The first column shows the basic tasks involved in our experiment and the specific indicators related to each of them are placed in the second column. But we have also considered for the design of our haptic interface that different tasks have different requirements, both the haptic device and the robot. For example, in the moving task, we need the game piece weight perception for the haptic force sensor, and also the grasping force provided by the corresponding robot sensor. Moreover, in our experiment, we get visual feedback provided by two cameras in the robot to determine the position of the game pieces so the operator can determine the necessary directions and trajectories to perform the desired task.

Figure 1 shows a summary of this whole process.

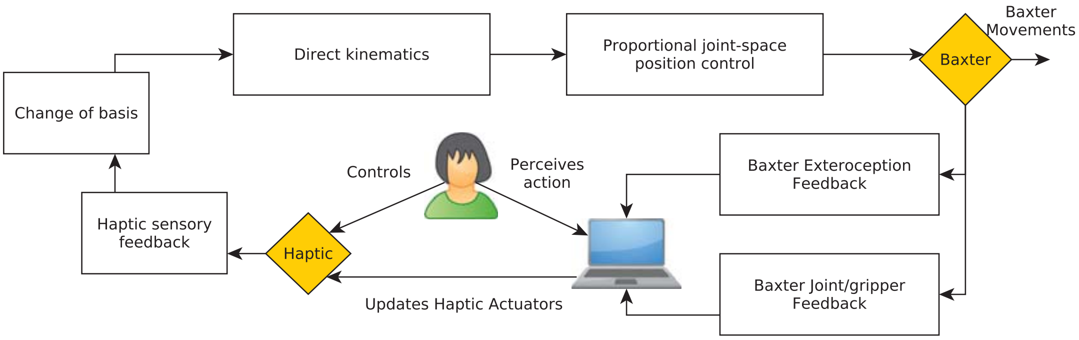

Fig. 1. Haptic-Baxter-Haptic control with human interaction.

IV. ENVIRONMENT DESCRIPTION

Any telemanipulation system is comprised of two robots, master and slave, and a communication channel that physically links them. The master allows an operator to send commands to control the slave's motion, while the slave robot interacts with the environment by executing such commands. Since the goal of this paper is to test if haptic feedback improves the user experience, the master robot must be a haptic device. To play a board game, the slave robot must be placed in a fixed location and be able to grasp and manipulate objects with precision. Our system is comprised of a Geomagic Touch haptic device and a Baxter robot acting as master and slave, respectively.

To perform the experiment, the environment needs to be placed where a board game can be played. The game mechanics must be as simple as possible, so that the user focuses on the manipulation aspects, i.e. grasping the game pieces and moving them along the board. Because Baxter needs a large workspace, the game board needs to be big enough; as well as the game pieces, in order to be easily grasped by the robot's end effector. After considering several options checker's game was selected.

The chosen environment is a room containing two separate tables: one for the Checkers board and one for the operator. The game's table contains the Checkers board and pieces. The operator's table contains the master device and a workstation. To ignore the communication channel time delays, both master and slave are connected to the workstation through Ethernet cables.

A. Master: Geomagic Touch

The master device needs to be able to send the operator's movements and commands to Baxter, but at the same time, provide some kinesthetic information to the operator, i.e. reflect the forces or vibrations sensed by Baxter. In the experiment's context, haptic devices capable of force feedback perfectly fits as a master device; particularly, we used a Geomagic Touch haptic device.

The Geomagic Touch is a 6 DOF device, that has 3 actuated DOF associated to the armature which provides the translational movements (X, Y, and Z Cartesian coordinates) and other 3 non-actuated DOF associated to the gimball that gives the orientation (pitch, roll and yaw rotational movements). Also, the device is able to perform a force up to a maximum of 3.3 N within a workspace of 160 (width) × 120 (height) × 70 (depth) mm. These characteristics are more than enough to both, translate the operator's movement using the device's stylus and feel the environment perceived by Baxter using the device's actuators.

The device is connected to a workstation running Ubuntu 14.04 (Trusty) with ROS Indigo. To communicate the haptic device with ROS, we used the package "*phantom-omni*" developed by Suarez-Ruiz [10]. However, this package was developed for ROS Hydro, so we adapted it and developed a new teleoperator program to control Baxter.

B. Slave: Baxter

The slave device needs to mimic the operator's movement and be able to grab or translate the Checker's pieces. For the experiment we used a Baxter robot (see figure 2).

Baxter is an industrial robot produced by Rethink Robotics. It was developed to enable collaborative human-robot co-work and enhanced Human-Robot Interaction. It consists of two seven degree-of-freedom arms, which provide kinematic redundancy that allows to enhance object manipulation. It comes with Series Elastic Actuators at each joint, incorporating full position and force sensing. Attending specification its max payload is 2.2 kg (including end effector) and a gripping force of 35 N. Baxter has several mounted sensors, one camera on each griper along with an infrared sensor range (4–40 cm), one camera on top of the robot display which is situated as a head and range finding sensors integrated on top of the robot. Baxter deploys an intuitive Zero Force Gravity Compensation mode that allows users to move each degree of freedom of both arms without effort.

The robot is connected to the same workstation as the Geomagic Touch. To communicate with Baxter, we used the ROS package "*baxter_pykdl*" from [11] which supports Indigo.

Fig. 2. Baxter grabbing a Checkers piece from the board.

C. Controller

To use the haptic device for the six DOF robot, the robot was split into two sets of three degrees of freedom. The first system is determined by the Cartesian coordinates of the wrist joint. The second one, the rotation of the gimbal, is then used to correspond to the three rotational degrees of freedom (Rx, Ry, and Rz) of the forearm of the robot. By doing this, the problems associated with multiple solutions to larger order degree of freedom robotic systems are mitigated.

We have used as an approximation the fact that the three axes intersect at the wrist despite the length of the link between the lower arm and forearm. This is justified due to the relatively short length of this link, and the fact that the robot is controlled based on the vision of the operator, allowing for intuitive compensation of the operator to position the end effector. This visual compensation is also used to mitigate the effects of motor backlash propagation through the robot, although other solutions to reduce backlash are being attempted.

1) Movement mapping: In order to interact with the environment, the physical movement of the haptic device must be properly translated to Baxter. For this work, only one haptic device is used, so the movement will only be mapped to one arm.

Position and orientation represent, at any time, the movements of an object in a space. Robotic mechanisms use the kinematic of the joints to represent their geometry, and thus, their workspace and movements. Both Geomagic Touch and Baxter have different joints (see figure 3). So, to link the movement from one to another, first we need to map their joints properly. However, Baxter's arm has more joints than Geomagic Touch, so some of its joints must be ignored to reduce the complexity of the movement translation.

Fig. 3. Corresponding joints of Baxter (top) and the Geomagic Touch (bottom).

Table II shows the joint mapping established between both robots. The whole arm movement is achieved as follows: to move in the X-axis, the "waist" joint is used; Y-axis is achieved by moving the "shoulder" joint; and Z-axis is moved by the "elbow" joint. However, these mappings are not enough, because for some cases, only half of the arm needs to move in the Y-axis, for instance, when trying to pick or drop a Checkers chip from the board. We solved this issue by using the "wrist2" joint.

TABLE II
JOINT MAPPING BETWEEN BAXTER AND THE GEOMAGIC TOUCH.

Baxter	Geomagic Touch
S0	waist
S1	shoulder
E0	Not used
E1	elbow
W0	Not used
W1	wrist2
W2	Not used

Even so, this mapping translates the movement, it is not correctly scaled as both robots use different workspaces, i.e. a large move for the Geomagic Touch is translated as a small move in Baxter. To fix this problem, we need to represent the haptic movement and orientation inside Baxter's workspace.

This is achieved by computing the proper transformation matrices for each joint. To bound the movements between the two workspaces, the transformation matrices will only use the scaling part, thus simplifying the calculations. Because each joint moves along a single axis, the problem is reduced to compute a scaling factor for each one (see table III),

TABLE III
SCALING FACTORS FOR THE MOVEMENT OF EACH JOINT MAPPING.

	Workspace bounds		
Joint Mapping	**Baxter**	**Geomagic Touch**	**Scaling factor**
S0→“waist”	3.2	1.96	1.63
S1→“shoulder”	2.24	1.75	1.28
E1→“elbow”	2.63	2.1	1.25
W1→“wrist2”	3.66	4.63	0.79

V. EXPERIMENT AND RESULTS

In this section we present the experimental procedure to analyse operator skills to move the game chip from one position to another one. We plan to play checkers in a robot - human game, but using teleoperation to control the robot.

A. Game description

Checkers is a strategy game board for two players that play on opposite sides of board. It can be played on 8x8, 10x10 or 12x12 checker boards. There are two kind of pieces: the dark pieces and the light pieces. The game consists in moving a piece diagonally to an adjacent unoccupied square. If the adjacent square contains an opponent’s piece, and the square immediately beyond it is vacant, the piece may be captured and taken away from the board by jumping over it. During the game, players alternate turns.

B. Board and game pieces adaptation

To accomplish our experiment, we modified the game board, game pieces and the gripper system of our robot. Baxter has two electric parallel grippers that allow our robot to pick up rigid and semi-rigid objects of many shapes and sizes. To play checkers we need these devices to be able to grab and move game pieces.

In real board games the shape of these pieces is cylindrical and they have a height of 3 or 4 and less of 25 mm of diameter. This is a big handicap because Baxter accuracy is only 5 mm.

For this reason, this first approach of the game proposes using 3D printer pieces. We have designed and fabricated cylindrical pieces of ten millimetres of height and 45 mm of diameter. Figure 4 shows the two elements manufactured by a 3D printer.

The chip has a slit in it to simplify the process of grasping, instead of pressing the piece from its external shape, the jaws are inserted into the slit and the gripper is opened instead of closed.

Finally, we have also modified the board and we made our own game board where the squares have a size of 55x55 mm, to adapt it to the pieces’ size.

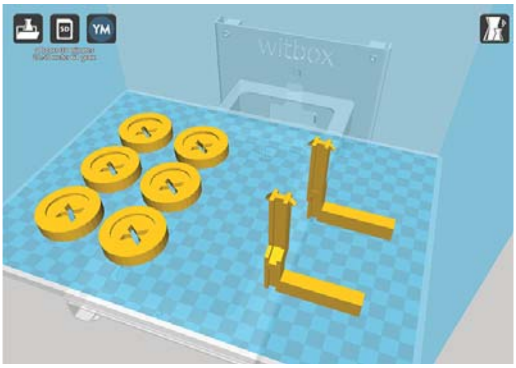

Fig. 4. Games pieces and grippers for print in 3D printer.

C. Experimental Workspace

An experimental workspace is defined in order to evaluate the users skills. The checkers game consists in repeating several times the actions of grasping a chip and moving it to another place on the board. Thus, we decided to generalize this task and perform an evaluation with a small group of users in order to understand their perception.

In this case, the workspace is a virtual orthogonal polyhedron situated in front of Baxter. The dimensions are a length of 75 cm and a width of 30 cm. The workspace is composed by two foam elements separated 15 cm from each other. It has two lateral panels to avoid visual contact from the operator. These elements are used to measure the collisions with the robot arm during the teleoperation task.

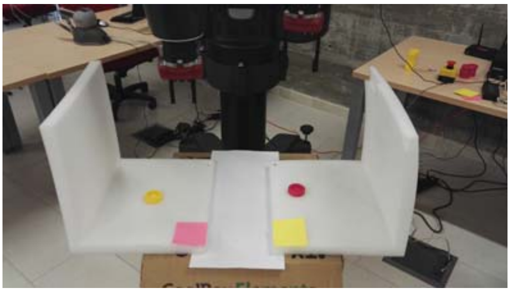

Fig. 5. Experimental workspace designed for the evaluation test.

Fig. 5 shows the workspace used during the experimental test. The user selects chip color before the experiment (yellow or pink) and she has to move one chip to the side marked with the same color.

The subjects of the experiment receive two sources of information: the haptic interface and the information from robot cameras. In this case, there was also an extra camera on top of the robot’s head for perceiving Baxter’s arm movements. Fig. 6 presents the information presented to each subject. Top-left image on the figure presents the camera available on Baxter’s wrist. Top-right image on the figure shows the workspace from Baxter’s head. IT provides a wide-view angle of the workspace. The terminal available on the bottom offers the distance from the arm wrist to the table.

D. Evaluation metrics

From the point of view of the evaluation, the concepts of usability proposed in ISO 9241-11 [14] are the ones considered: effectiveness, efficiency and satisfaction. The effectiveness will evaluate if all subjects are able to accomplish the task with the expected result. The efficiency will evaluate if the subjects accomplish the task with the least waste of time and effort. In this case we are going to measure the time and the collisions with the lateral planners. Finally, satisfaction value has to consider both robot and haptic devices. In that manner, we measure aspects like collaborative metrics [12] in order to analyse human-robot interaction and human-haptic interaction. This feedback is given by a questionnaire performed by all the subjects of the experiment.

E. Evaluation results

A group of nine subjects was chosen. They were familiar with the use of haptic devices: seven subjects were technical people and two subjects were the developers of the application. Table V-E shows the quantitative results. There is a difference of 37 seconds between the fastest technical operator and the fastest developer.

TABLE IV
RESULTS OF THE EXPERIMENT

Subject	Time (sec.)	Collisions	Specification
1	57	2	Technician
2	60	0	Technician
3	161	3	Technician
4	50	0	Technician
5	70	0	Technician
6	55	0	Technician
7	90	0	Technician
8	23	0	Developer
9	13	0	Developer

Analysing these results we can see that the developers of the experiment have completed the task much quicker than the other participants. Thus, taking only data from the first seven subjects in the experiment, we can see that the average time to complete the task has been 77,5714 seconds and a standard deviation of 39,1256 seconds (see table V).

TABLE V
DESCRIPTIVE STATISTICS FROM HUMAN-ROBOT EXPERIMENTAL RESULTS

Description	Result
Subjects	7
Mean	77,5329s
Standard Deviation	39,1256s
Minimum Time	50s
Maximum Time	161s

F. Questionnaires

Finally, eight of the participants replied to a set of questions for a subjective evaluation of our research. Table VI presents the results.

The results were positive except on the question, *How natural did your interactions with the haptic device seem?* where the users expectations are different in terms of normality against other devices as a video game pad.

In their comments, the subjects asked to add more force feedback in the haptic device and more information about the distance from the gripper to the board game on the table.

VI. CONCLUSION

This papers presents an experiment for teleoperating a Baxter robot by means of a Geomagic Touch haptic device. The task to be performed is playing Checkers, and the goal is to know if getting haptic feedback improves the user experience.

The designed environment includes the haptic device in the master role and Baxter in the slave role. An adapted board and chips were used for nine users to perform two basic tasks: dragging and raising a chip. Besides the metrics used for the quantitative evaluation, a questionnaire was also used for the qualitative evaluation.

The results obtained by using the GEHID guide, show that the users that are new to the system, that is, the ones that are not the developers, do not find the interaction to be natural. They also suggest adding more force feedback in the haptic device when the robot is dragging or holding a chip. They propose including more accurate information about the distance from the gripper to the board game.

In future work we will try to improve the correspondence between the haptic device and Baxter's arm movements in order to make them more natural. We will test several force feedback information and improve the operator's interface for offering more precise information. We are also considering comparing this environment to a parallel one using a leap motion device for testing if the sense of touch improves the user experience. To do so, we need to compare an environment guided by haptic response to another one based only on graphical information.

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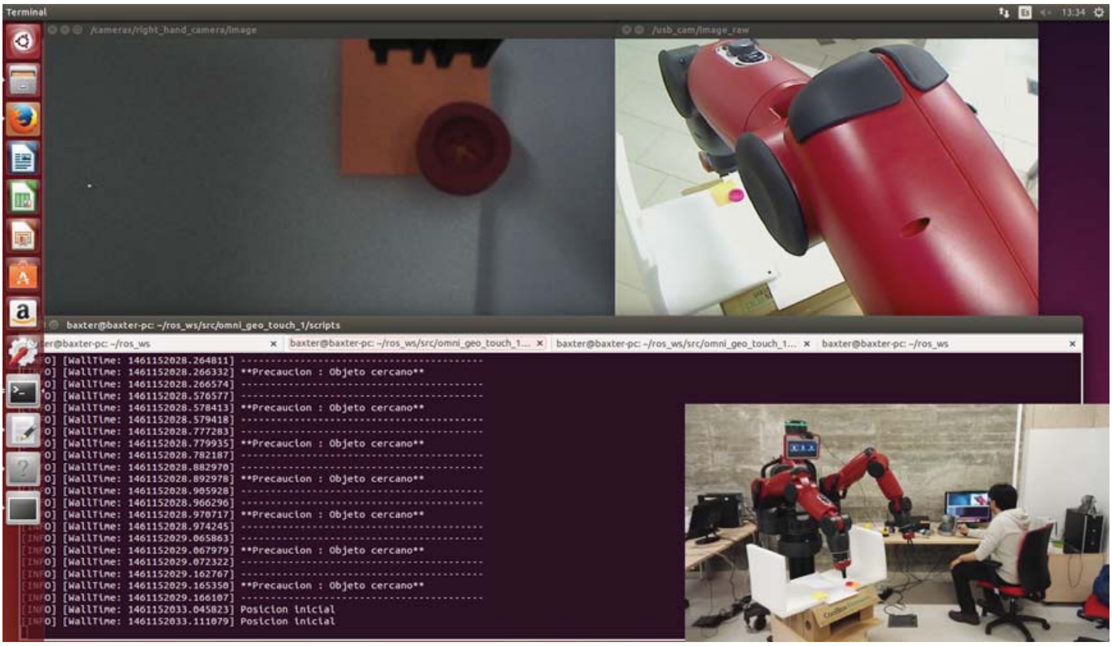

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Fig. 6. Information presented to each subject during the test.

TABLE VI
RESULTS OF A QUESTIONNAIRE USING A LIKERT SCALE:1 NOT AT ALL - 7 EXTREMELY

Questions	Average
How much were you able to control arm movements with the haptic device?	4
How responsive was the robot to actions that you initiated (or performed) with the haptic device?	4.25
How natural did your interactions with the haptic device seem?	3.375
How much did the visual perception of the environment help you to perform the task of grasping the chip?	4.875
How compelling was your haptic sense while the robot was grasping the chip?	4.857
Were you able to anticipate what would happen next in response to the actions that you performed?	4.375
Before the experiment, do you feel the experiment like a waste of time?	1.5
After the experiment, do you feel the experiment like a waste of time?	1.125
What type of board game would you like to play with a robot?	checkers (3), Chess (3), Other (1)
In which role do you like to play?	remote operator (3), opponent (4), both (1)

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