Remote Laboratory on Mobile Robotics TeleMobileRobot-Lab

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Abstract. *This work presents the Web enabled remote laboratory TeleMobileRobot-Lab developed as a project for supporting the execution of remote labs in Mobile Robotics courses. This laboratory is designed under a client-server architecture where the access to users is enabled through Web clients connecting to a server to perform tele-operation tasks. Each remote lab experiment is performed by a user under a test scenario which also allows access to Observer users. The laboratory allows simultaneous execution of remote experiments on different test scenarios. The current remote laboratory supports robots from the MobileRobots Inc manufacturer and it is evaluated through tests applied to users obtaining results of functionality, and usability.*

1. Introduction

Hands-on, simulated, and/or remote experiments in specialized courses are an important part in the learning process of students because this experience helps that the theoretical knowledge acquired in class be put in practice and enforced with the purpose to achieve a clearer understanding [Ma and Nickerson 2006]. From the beginning, man has understood that the practice is the best way to consolidate knowledge, and therefore many philosophers and thinkers of history have alluded to this topic. We bring a famous phrase of the philosopher Confucius: "*I hear and I forget. I see and I remember. I do and I understand.*"

On specific topics such as robotics, experiments require some infrastructure of robots, sensors, instruments, and computers that are sometimes difficult to be available to the students. This prevents the development of hands-on labs because of the infrastructure unavailability. In most cases, research, training, and learning centers have the infrastructure for the development of experiments, but many of them have restrictions such as the availability of the laboratory (e.g. restricted time schedule), the physical lab space, the physical presence of the students, assistance by a technician or engineer, and single (i.e. non-simultaneous) working sessions due to limitation of the equipment. The proper use of a physical laboratory for the students is then limited by the previous restrictions. This set of constraints suggests a change in how to perform laboratory experiments. So to make the best use of the laboratory equipment is expected the removal of the spatial and temporal barriers and others constraints, enabling students and teachers to develop laboratory experiments. From this issue, the development of remote laboratories on mobile robotics aims to provide a solution to the problems of accessibility to equipment for the labs. It also seeks to solve problems concerning the laboratory schedule, since in most cases the opening hours are related to the presence of a technician who is aware of the development of experiments and/or the use of equipment.

This paper proposes the use of the remote robotics TeleMobileRobot-Lab as a tool for educational robotics, and explains its characteristics. As a result we have a laboratory which aims to provide a solution to the above problems. This paper intends to provide an overview of the solution, starting from the analysis stage, through the design, implementation, and testing phases.

The remainder of the paper is organized as follows. In section 2, we discuss some work related to the development of remote laboratories on articulated and mobile robotics. The description of the development stages of the TeleMobileRobot-Lab is presented in section 3. Section 4 reports testing results of the remote laboratory. Finally, the section 5 presents the conclusions and future work.

2. Related Works

The development of remote laboratories on mobile robotics intends to deal with common problems outlined above, so it is of interest to opt for the development and implementation of such laboratories.

Rosado *et al.* (2008) developed a Web platform based on simplicity and easy understanding that allows students to do engineering experiments in articulated robotics remotely through a web browser. Their work was based on the development of a remote laboratory with the following characteristics: not requiring any human presence for the development of laboratory experiments, to achieve maximum robot availability, to build a robust system able to detect risk events for the robot, to implement a project economically viable in future, to develop a system that avoid problems that jeopardize the security of the robots, and to provide the correct and necessary information for proper learning. At the development level, the user interface was developed entirely in PHP and uses a MySQL database for storing configuration data of the overall system. In addition, a Siemens CP343-1IT card is used for the hardware control of the system allowing control of robots and other hardware items. The result is a remote Web laboratory that allows users, after authentication, to use high-cost industrial robots through a reservation system. The laboratory allows the use of a robot for a period of 30 minutes, also is able to compile and execute RAPID (programming language used to control industrial robots) files loaded by the user in the robot. The system has access to exercises, so that each robot has a number of experiments that can be chosen and developed by a student. Finally, the system provides sensory information from the robot and a range of IP camera views with the current view of the robot.

The work of Caicedo *et al.* (2009) allows the development of experiments remotely in robotics laboratories at two universities. The first laboratory for industrial robotics is equipped with a Mitsubishi RV-2AJ robotic arm. The students are allowed to do tele-operation tasks and to program the robot remotely. The second laboratory for mobile robotics is equipped with a Pioneer P3-DX robot in which students can perform tele-operation tasks and tracking of trajectories. This work shows benefits to sharing robotics facilities between universities such as reduction of investment costs in infrastructure, promotion of joint work between universities, and expansion of the technological coverage for students that could not use these kinds of laboratories because of economic and/or geography reasons.

Abdulwahed and Nagy (2011) present a laboratory having three access modes: virtual, on-site and remote. The paper mentions the advantages and disadvantages of each modality. The on-site laboratory has the great advantage of its high level of fidelity and realism, but it is criticized for his lack of opportunities for demonstrations to other research centers because of economic and logistics reasons. The virtual mode has the great advantage of having greater ability to repeat experiments, providing an interactive experience in which students can practice outside the classroom, however, as a major disadvantage, the virtual laboratories simulate robots but cannot fully model all the physical phenomena. Finally, the remote labs have the ability to share resources with other universities or research centers and reduce the economic cost of implementing new platforms, but have the disadvantage that remote users cannot use the full range of functionality available in an on-site laboratory.

The work of Candelas *et al.* (2004) focuses on using two virtual laboratories to evaluate the acceptance that they have in teaching robotics in a university context. The first laboratory is called VISION and it is a virtual environment for simulation of machine vision algorithms. The second laboratory, called ROBOLAB, was used for simulation and tele-operation of an industrial robot. The study results identified the significant problems in using virtual laboratories (Figure 1). An interesting finding is that in the 54% of cases there are no problems in the use of laboratories, but must be given special handling in the laboratory response rate, in the ease of access to laboratory networks and the use of the Java Applets.

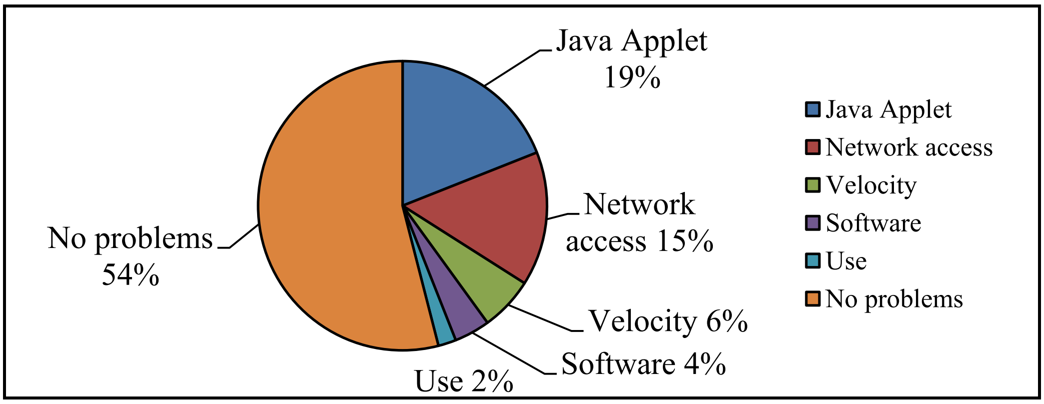

Figure 1. Detected problems when using virtual labs [Candelas *et al.* 2004]

Finally, Cooper and Ferreira (2009) present an analysis of main aspects related to the use of remote laboratories in Science and Engineering. The authors highlight the aspects of: The set-up of remote facilities to be accessed by students and teachers, the learning content and activities related to the remote experiments, the teacher and student training for making good use of facilities and the content, and the pedagogical evaluation. The results presented are the result of the experience gained by authors during the development of remote laboratories under several pedagogical projects (PEARL, MARVEL, Labs-on-the-Web, and Lego Mindstorm-based remote labs). As a conclusion, the authors presented the key lessons learned to take into account for designing and using remote laboratories in pedagogical activities.

3. Laboratory TeleMobileRobot-Lab

The web enabled remote lab on mobile robotics TeleMobileRobot-Lab is developed having the previous works as reference. Its main goal is the development of a remote lab to offer connection to multiple users, so they could perform tele-operation tasks, each user working on a different test scenario with a mobile robot. Its development comes from the idea of a simple design that allows a high modifiability to improve integration of new functionalities. The project mainly centers in the robot tele-operation functionality.

3.1. Base platform

The objective is to build a web platform through which users can tele-operated remotely robots that are located physically in a lab. The platform allows define multiple testing scenarios that correspond with a configuration of a unique mobile robot and a set of IP video cameras available in the physical lab. The tele-operation mode of the remote lab provides an interface that let the users drive the mobile robot forward, backward, left and right directions. Besides it also has a stop button to stop the movement of the robot. The tele-operation interface also provides feedback of the sensorial data obtained by the robot (ultrasound sensors and a URG-04LX laser range finder). Finally, it also has a feedback of the current view of the robot given through an onboard camera and others cameras installed in the physical lab.

3.2. Analysis stage

At this stage the desired requirements were analyzed based on the related works, the software architectures already proven and the technological restrictions imposed by the hardware available in our laboratory.

First of all, the functional and non-functional requirements of the system were analyzed. According to the basic features of the platform, the concept of test scenario is introduced: each test scenario consists of a single mobile robot (with unique IP address) with its own sensors and a set of IP cameras (in our case, we use D-LINK DCS-5220 cameras). The cameras include a camera onboard the robot and others installed in the laboratory. In addition, a test scenario defines the feedback information that can be presented to users. A test scenario allows the connection of a single user. Once the platform gives a user access to a test scenario, it provides an interface for the tele-operation of the respective robot with the data of its sensors. The platform offers the possibility that different users have access to different test scenarios simultaneously: each user working on a specific scenario. Thus, the platform allows define test scenarios depending on the hardware resources available in the laboratory and on the purpose of the tele-operation task that each user wants to develop.

Given the relationship between users and test scenarios, the remote lab platform provides user management tools (user creation and user authentication), and configuration/creation of test scenarios. The platform manages three classes of users, each one defined by a profile which has assigned different responsibilities and permissions. These profiles are: administrator, user and observer. The administrator profile allows configure the system (remote laboratory), in particular the configuration of its users and the test scenarios. The user profile allows connection to a test scenario to develop a tele-operation experiment in the remote laboratory. Finally, the observer profile lets show the view of the IP cameras attached to a test scenario, without the possibility of tele-operation, just observing experiments in the laboratory. This last profile provides web-based demonstrations to a group of students or people connected remotely.

The following non-functional requirements were considered: The performance of the tele-operation, reflected in the speed of the execution of the tele-operation commands sent and the update of the sensorial data to the user; the availability of the platform in order to maximize the time of use of the resources available in the laboratory; and the extensibility of the system, so the platform can be enhanced easily in the future.

3.3. Design stage

In this stage is important to analyze the technological constraints given by the types of robots available. First of all, in our laboratory are available Pioneer P3-DX and AmigoBot robots of the MobileRobots company whose development and connection APIS are available for the C++ and Java programming languages under the Aria and ArNetworking libraries. Currently the servers for the connection are limited to the use of one of these two languages. The IP cameras can be accessed under the HTTP protocol and its control is made with REST requests. For reasons of uniformity and consistency in the development of the remote laboratory, the connection layer with the robots was implemented in Java and the web layer was implemented in PHP. The software architecture takes into account the attribute of extensibility of the system, so it was opted for an architecture based on modules that can end up in a flexible software, which can add, remove or modify any functionality without a high impact on the system (Figure 2).

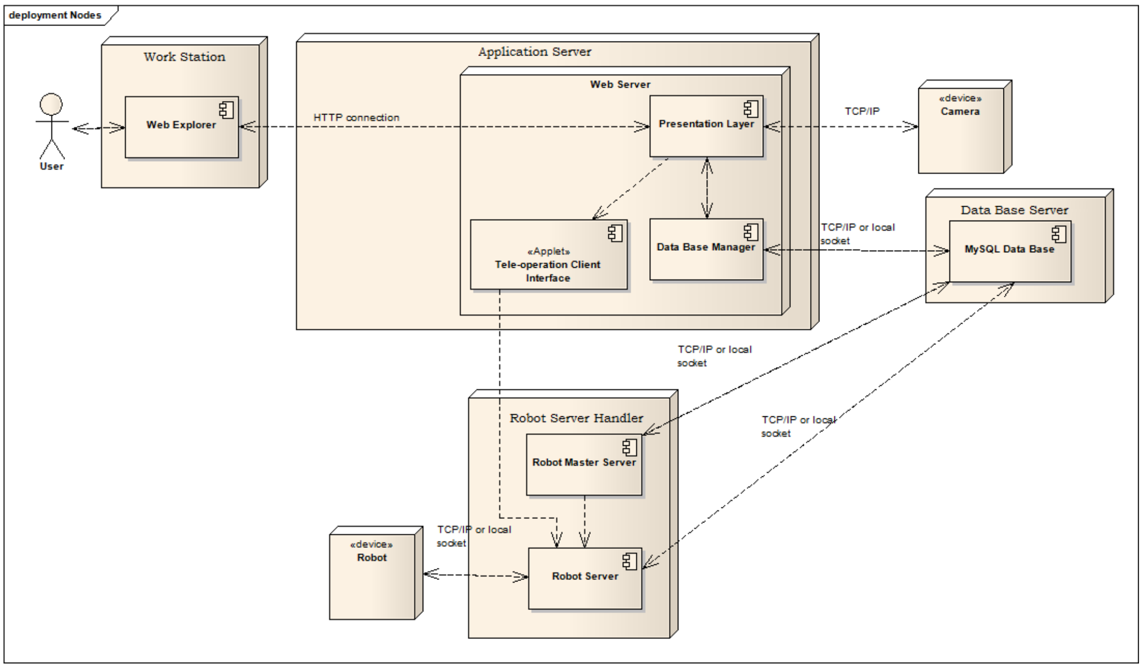

Figure 2. Software architecture design of the proposed platform

On the client side of the platform, each user uses a web browser to connect to the remote laboratory. On the server side, a module is designed for the presentation layer which also connects to the modules of the client interface of tele-operation for interaction with the robot and to the handler module for database access control to the system and test scenarios. The client interface module of tele-operation is connected to the server of a robot which is responsible for managing the protocol with the client and pass instructions directly to the robot. On the other hand, there is a master server of robots using a technique called heart beat that checks the server status verifying if the program is not running and launching the program again on detection of a failure. This was made to ensure the availability in the service.

3.4. Implementation stage

The main modules of the implementation of the TeleMobileRobot-Lab system are explained next (Figure 2).

Robot server (developed in Java) is responsible for serving as a mediator between users request coming from the web layer and the robot in a test scenario. The robot server is also responsible for transforming user requests into commands for the robot. Each scenario must have a robot server configured to manage the respective robot.

Robot server master (developed in Java) is responsible for verifying if a scenario has available a robot server to meet client connections. The server knows the status of the robot server using the heart beat technique and in case of failure, this launches a new server to ensure the availability of the system.

Tele-operation client interface is associated to the web presentation layer of the system and consists of a Java applet able to connect using TCP sockets to the robot server of a scenario chosen by the user to develop his/her tele-operation experiment. Besides, it is also responsible for sending commands to the robot server of tele-operation.

At this point is worth noting that the connection program with the robot that has loaded the robot server for tele-operation is based on a behavior control architecture. It supplies a special emergency behavior with higher priority than other behaviors aimed at stopping the robot in case of imminent collision. This provides security to the robot in the development of experiments.

Database Manager is the module in charge of connecting with the database, and it serves as a bridge between the web layer and the storage of information. This module manages connections to a MySQL database which stores all information concerning to the users of the system and test scenarios.

Presentation layer (developed in PHP) provides the user interface for system administration, the menus for selecting scenarios, and the development of tele-operation experiments, handling for example the HTTP requests for the manipulation of the IP cameras set up in each scenario. This module uses information in the database for the deployment of the web interface based on the user and its profile.

4. Results

In this section we are going to show the final result of the implemented platform. When a user logs from a web browser to the platform, the user is received in the lab homepage. On this page the user can login at the laboratory or the user can register when he/she does not have an account at the laboratory. Figure 3 (left) shows the homepage of the laboratory. When a user wants to perform a laboratory experiment, the user can choose from multiple test scenarios previously configured by the administrator of the system (Figure 3 right), each scenario allows a user to connect a robot to perform a tele-operation task. If an user is already connected on one test scenario and another user attempt to connect simultaneously, the laboratory will allow the access of the second user only as an observer who could see the IP cameras configured on the test scenario.

Figure 3. (Left) TeleMobileRobot-Lab home web page. (Right) Selection menu of scenarios configured by the Administrator.

As an example we will show you a remote laboratory configuration in which there are two test scenarios (Figure 4), one of them with a Pioneer P3-DX robot with ultrasonic sensors and a URG-04LX laser sensor, the other with an AmigoBot robot with only some ultrasonic sensors. Both robots have an IP camera on board. Only one user could tele-operate the robot configured in each scenario but many other users could connect to the scenario as observers.

Figure 4. (Upper zone) Scenario 1 with Pioneer P3-DX robot. (Lower zone) Scenario 2 with AmigoBot robot.

One of the users is connected to the first scenario and can tele-operate the Pioneer P3-DX robot (Figure 5). In the top panel of the user interface, the user has a view that shows the configured IP cameras on the scenario. The panel includes buttons (right/left) to change the camera of interest. Each camera can be rotated in four directions (right/left, up/down), this in order to visually explore the environment for tele-operation. Furthermore, within the user interface, a map exists with the readings of the proximity sensors of the robot. This robot has an URG-04LX laser sensor, so the map shows detected points with high precision (accuracy 3% of measurement, angular resolution 0.36°), these points are represented by green dots on the map view (middle panel). The map has a grid to measure the approximate distance at which the robot is from a particular object. The user also has the current status information of the robot (lower left panel), given by the battery status, translational and rotational speeds, odometric distance, odometric time and the odometric degrees. Also the user has buttons to send motions commands to the robot (right/left, forward/backward, stop) (lower right panel).

Figure 5. User interface for test scenario 1 with a Pioneer P3-DX robot with ultrasonic sensors and a URG-04LX laser range finder.

At the same time another user is connected to the second test scenario configured with an AmigoBot robot (Figure 6). This robot has only eight ultrasonic sensors, and therefore the map displaying sensory data is limited due to the limited number of sensors and the imprecision and low resolution of the readings received by this type of sensor. However, these sensors are useful in the detection of near obstacles which can activate the emergency behavior to avoid collisions.

4.1. User testing

To evaluate the performance and usability of the TeleMobileRobot-Lab, we applied a test to ten undergraduate students; the aim was to develop a tele-operation task, in which each user had to operate the Pioneer P3-DX robot from an initial point to a final position (Figure 7). This test scenario had been configured with two IP cameras: an onboard camera and a fixed camera looking at the environment of the tele-operation task.

After the test, we conducted a survey about the usability and functionality of the platform. Each student gave his/her opinion about five statements, each of them could be rated from 1 to 5 where 1 means be completely disagree, 2 disagree, 3 nor disagree nor agree, 4 agree, and 5 completely agree. The results for each statement are shown from the Figure 8 to Figure 12.

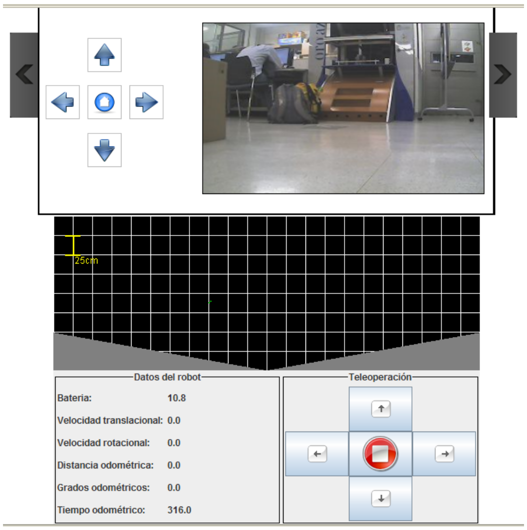

Figure 6. User interface for test scenario 2 with an AmigoBot robot with ultrasonic sensors.

Figure 7. Test scenario for the tele-operation task with users. The red dot marks the final position of the task.

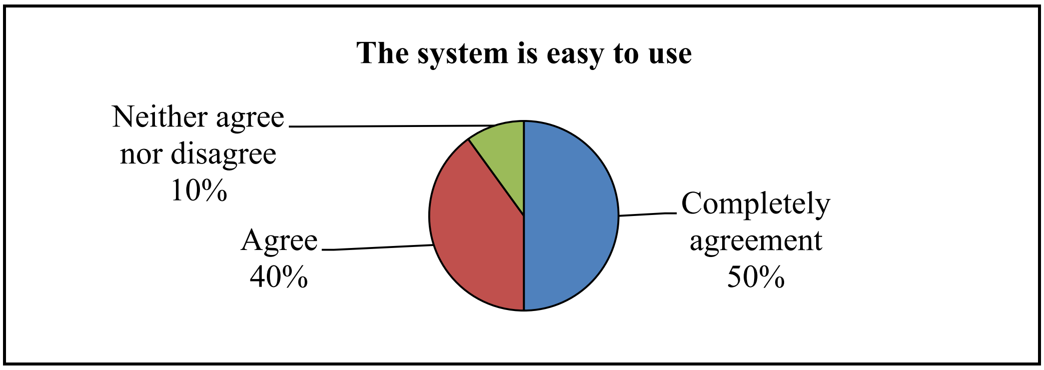

Figure 8. The system is easy to use.

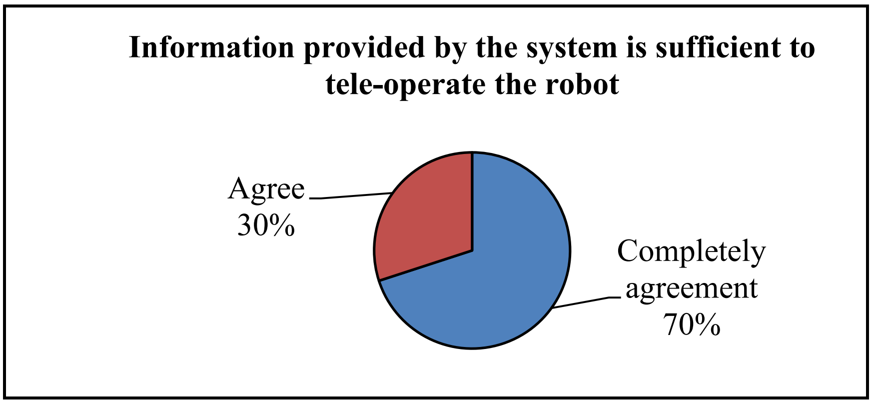

Figure 9. Information provided by the system (video, map with sensor laser and ultrasound readings, robot information) is sufficient to tele-operate the robot.

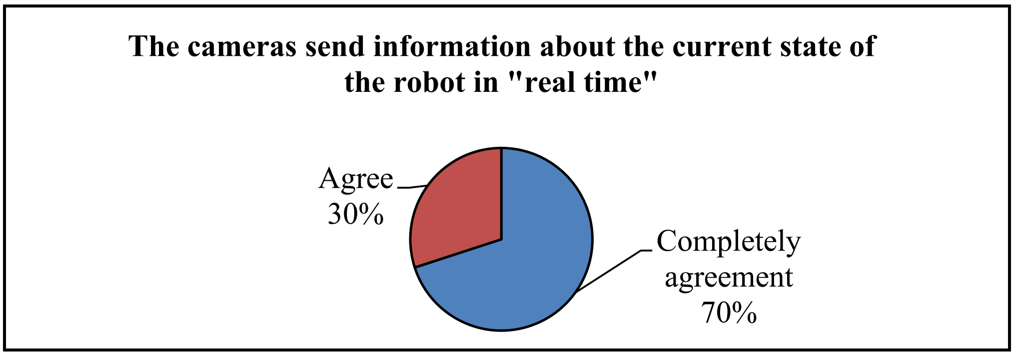

Figure 10. The cameras send information about the current state of the robot in "real time".

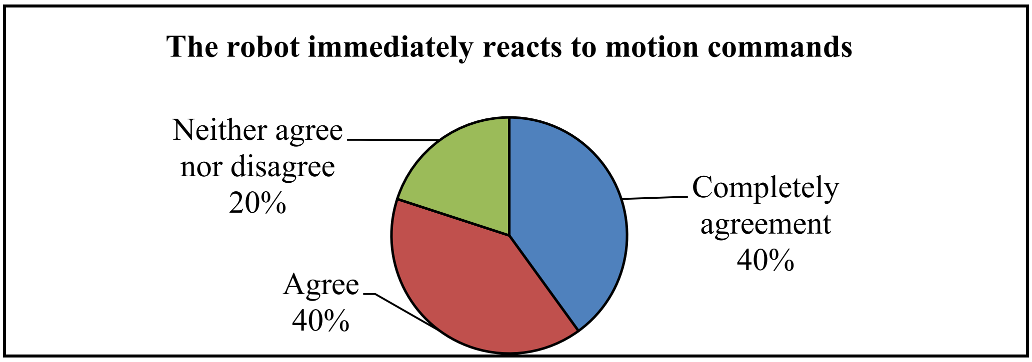

Figure 11. The robot immediately reacts to motion commands (i.e. the user feels that the robot receives commands, execute and visualize them simultaneously).

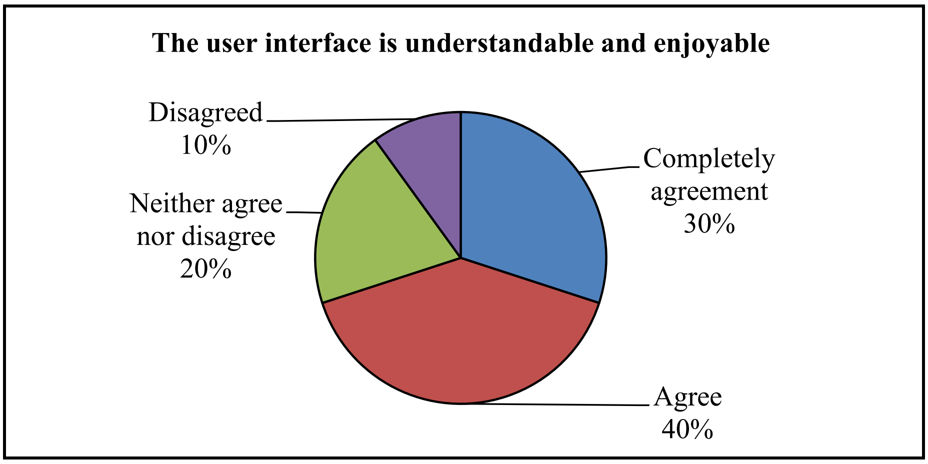

Figure 12. The user interface is understandable and enjoyable.

5. Conclusion and Future Work

The remote laboratory TeleMobileRobot-Lab provides access to multiple users for tele-operation remote experiments; each user working on a different test scenario. Each user has feedback data from sensors of the mobile robot and the IP video cameras set-up on each test scenario. It is noteworthy that the remote laboratory exploits the best the available infrastructure in the physical laboratory, allowing access at any time of day, from web browsers with an Internet connection. However, the assistance by a technician in the laboratory is necessary in special cases (e.g. recharge of robots, reconnection of robots by network interruptions). In general, according to a survey applied to undergraduate students about the remote laboratory proposed, the aspects evaluated show a high satisfaction of the students to perform a tele-operation task. These results identify pros and cons of the proposed remote laboratory, and help us to identify possible improvements for the current platform.

In the future work, we plan to work in three aspects. The first one is the usability concerning the tele-operation task. The idea is offering a more comfortable experience by using interaction devices such as keyboard, common joystick, and steering wheel. On the other hand, the map with sensor data is an important source of information for the users that can be improved in quality. The second aspect is the pedagogical aspect. It is important to use the proposed remote lab to support experiments in the mobile robotics course. For this, it is important to complement the tele-operation tasks with an evaluation process. This process includes identifying relevant elements and topics to be evaluated from the experiments, and to define the evaluations to be applied to the students. The last aspect concerns the definition of a new functionality which allows the uploading and execution of supervised tasks. This new functionality extends the space of possible experiments available from the remote lab to the students and teachers.

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