Experimental Evaluation and Pilot Assessment Study of a Virtual and Remote Laboratory on Robotic Manipulation

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Abstract — **Practical training in experimental laboratory scenarios is indeed of great importance since mere lecturing is not sufficient enough to complete students' education in many engineering disciplines. Synchronous and asynchronous distance learning platforms have many advantages such as attending courses from a distance (e.g. in virtual classroom environments). However remote "e-laboratory" systems are just now beginning to develop. In this paper, the development of a "virtual and remote laboratory platform" in the field of robotics and the methodology of its experimental evaluation are discussed. In the past, in our prior work [10], a first pilot experimental study was conducted according to a special evaluation protocol, in order to evaluate system performance regarding remotely training students to program robot manipulation tasks using the robot's Teach Pendant. The results of the first pilot study are encouraging enough. In this paper, we are focusing on the methodology of the evaluation protocol and discuss ways to extend this study amongst three groups: group-I trained the "classical way" on the real robot, group-II (remote) trained remotely on the graphical user interface of the remote laboratory platform, and group-III (virtual) also trained on the user interface, but using only the "virtual robot" functionalities of the platform with no remote real robot connection on the loop. Initial results are showing the need for developing real training scenarios in the frame of remote laboratory education aiming to achieve effective learning schemes for students in the engineering field.**

I. INTRODUCTION

During the last decade, many "distance-learning" platforms and applications have been developed, to enable teaching from a remote location in a synchronous or asynchronous e-learning mode. The development of such applications is often based on some type of tele-conferencing (video/audio streaming) platform, with an MCU (multi-point conferencing unit) at the core of the system, enhanced by many software features, such as application sharing or other functionalities forming "virtual classroom" web-spaces. We can, thus, acknowledge that nowadays attending and participating in classroom lectures or seminars remotely is a technologically feasible goal, since related technologies are mature enough and many application platforms have already been established as a standard.

Nevertheless, one should consider the fact that exchanging audio/video streams, sharing educational material (such as presentation slides) in a synchronous or asynchronous way, or interacting in a "virtual classroom" space are often not adequate enough to complete an efficient educational program. A typical example is teaching in engineering disciplines, where hands-on laboratory experimentation is still considered to be irreplaceable and absolutely necessary for enhancing and completing classroom lectures. As a result, we believe that studies focusing on the development of "virtual and remote laboratory platforms" and the methodology of their evaluation could give valuable information concerning the design of an effective educational program through an experimental laboratory training process suitable for students in the engineering field.

A number of "*virtual laboratory*" projects have been initiated in this context on a national or international basis worldwide during the last 4-5 years (e.g. the ReLAX project [1], the CyberLab network [2], the eMersion project [3]), aiming to teach fundamental concepts in different engineering fields through the remote operation and control of specific experimental facilities. The current study discussed in this paper, as compared with the aforementioned research efforts, differentiates in the following three dimensions:

1. At a *technological level*, the platform integrates a number of different control modes inspired from advances in the field of telerobotics (such as direct teleoperation or indirect robot teleprogramming), including an accurate emulation of the robot-programming controller (in our case the robot's "Teach Pendant") as well as a realistic representation of a robot laboratory setting in a virtual reality simulation panel.
2. At an *educational/training level*, building on the aforementioned control modes and functionalities, the platform is employed in realistic training scenarios, to assist students realize and learn how to operate the real system, and acquire skills associated with the programming of the real robot.
3. Finally, at an *experimental evaluation level,* a series of experimental studies was followed amongst different student sub-groups regarding the type of

their training, based on the construction of a special evaluation protocol which combines qualitative and quantitative ratings; our aim is to distinguish different ways of training and instruction design in the engineering field, with two main dimensions: the classical/real experimental training vs. the remote and/or virtual laboratory training.

At the current stage, the first pilot study has been completed and the initial results are of great interest revealing that there is a need for enhancing the training of student engineers with realistic scenarios in laboratory environments. The study following on shows that high learning attainment can be achieved by students if their training is based on what we name Realistic Structure Learning Design scenarios (RSLeaD).

As it is known, the Structure Learning Design for engineers (SLeaD) assumes that instructors are responsible over developing and deploying specific procedures to provide an effective and productive learning experience for their students. According to this model, the new learning paradigm principle is that "Learning is conceived of as something a learner does, not something that is done to the learner" [11, 12]. In the same direction, Modern Pedagogy gives emphasis on the student-centered model of Learning. In addition, one of the principles of the SLeaD, points out the need for experiential tools; this means that modern technology includes simulation, emulation and web-enabled control systems; such a technology is designed to enhance research tools, labs control, interactive learning and evaluation. Another significant principle of the SLeaD is the one that emphasizes the role of research on students' learning. Furthermore, the development of an effective evaluation procedure constitutes a continuing process, offering valuable feedback information about the students' learning and training " [11]. RSLeaD is based on the SLeaD, with a great emphasis on the experiential training of students through relevant realistic learning scenarios and on the evaluation of this training as an integral part of the whole training scheme.

II. VIRTUAL LABORATORY TRAINING OBJECTIVES AND LEARNING SCENARIOS

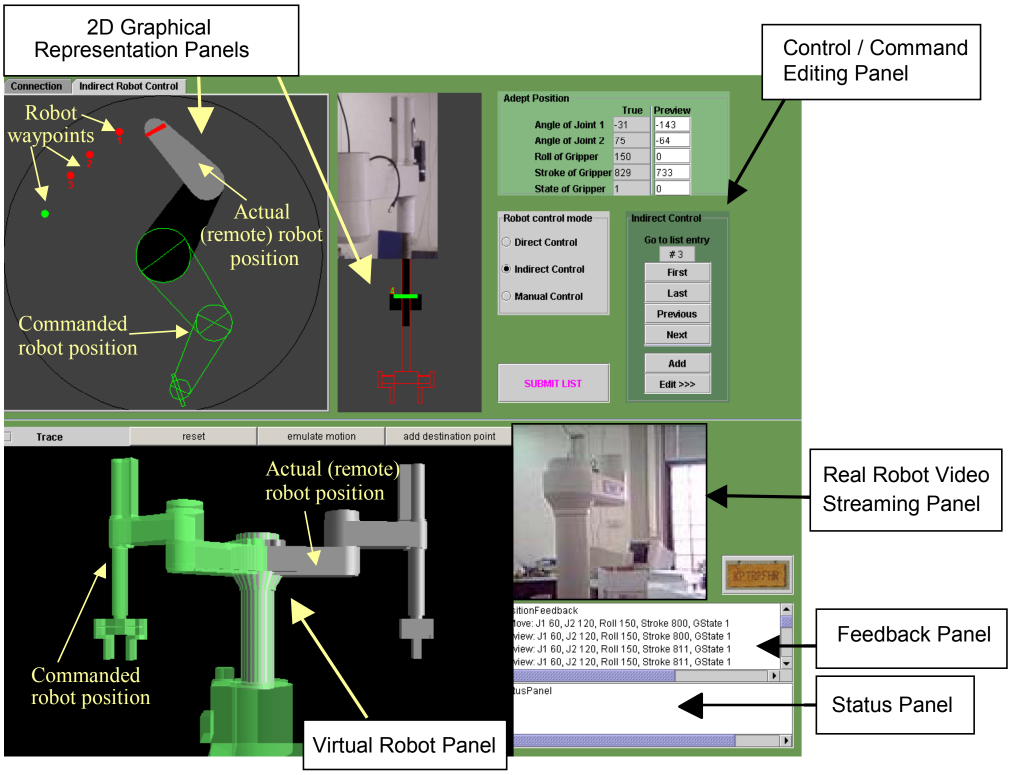
The general aim of our work is the development of a virtual and remote laboratory platform to enable student training in robot manipulation and control technologies from any remote location via Internet. Access to robot manipulator arms and other similar mechatronic devices and laboratory equipment is often either limited by specific time restrictions or even not provided at all. One prohibitive factor is the high cost of such equipment, which makes it very difficult for many academic institutes to provide related laboratory training courses in their educational curricula for engineers. Therefore, the benefits from providing a means for any-time/any-place (virtual and/or remote) experimentation in a "lab facilities sharing" context are evident from a socio-economic point of view, apart from a pedagogical point of view related to the completeness and quality of practical training possibilities offered to their students.

Existing virtual or remote laboratory systems are very few, as it was discussed in the prior section, and provide some limited functionality in the sense of: (i) simulating and animating (in 2D or 3D) the motion of simple robot arms, (ii) practicing movement commands, which are usually issued either as desired end-effector's position in xyz coordinates, or even directly as desired angles in the robot's joint-space, and eventually (iii) submitting these commands for execution by a remotely located real robot. Such functionality indeed demonstrates and teaches students the basic principles of robot manipulation and control. However, programming a real robot arm to perform a specific manipulation task (e.g. a pick-and-place task in an assembly sequence) is usually somehow more complicated than all these. The human operator should often resort to programming the task directly using the robot's own programming language (usually some script-like interpreter language, such as VAL, V+ etc.); usually, however, an on-line robot programming scheme is employed, for instance using the robot's Teach Pendant tool, in order to teach (record) the intermediate configurations that will constitute the complete robot motion sequence.

Taking into account these considerations, we directed our work towards the development of a virtual robot laboratory platform that will train students on how to program a robot manipulator arm, using the functionality and programming modalities provided by the real robotic system. The platform developed incorporates a robot's Teach Pendant emulator, as well as a virtual 3D robot animation panel integrated in the graphical user interface. The system enables students to create, edit and execute robot programs (i.e. complete motion sequences, such as a pick-and-place task), in exactly the same way as they would if they were using the real-robot's pendant tool. The program created can be previewed "locally" by the student/trainee in 2D and 3D animation modes, and can then be sent for execution: either (a) by the virtual robot simulation, incorporated as mentioned above in the graphical user interface, or (b) by a real, remotely located, robot manipulator (such as the SCARA-type Adept manipulator located in the premises of our robotics and automation laboratory), with actual video streaming feedback provided to the user. Other real robot programming modalities, such as direct text editing and remote execution of program code in the robot's own programming language, could also be implemented and are considered for integration in the near future.

Thus, the key issue to be emphasized is the support of real robot programming modalities within a virtual and/or remote laboratory platform, with the main objective being to provide students with realistic practical training on how to actually create and issue a complete robot manipulation program in a real-world task scenario. In this context of deploying a virtual and/or remote laboratory platform for robotics, our research is currently focusing on the following two main issues:

(a) From a *technological point of view*, we focus on the adaptation of concepts and techniques developed in the field of telerobotics and on exploring their implementation in such remote laboratory settings. Robot teleoperation technologies have been constantly advancing and evolving for more than two decades now [4, 5]. Initial teleoperation systems were deployed in dangerous and hostile environments (e.g. in the nuclear industry for the telemanipulation of radioactive material). The advent of communication and networking technologies, as well as the development of new human-machine interactive simulation media (such as virtual reality systems [6]),



Adept Position

	True	Preview
Angle of Joint 1	-31	-143
Angle of Joint 2	75	-64
Roll of Gripper	150	0
Stroke of Gripper	829	733
State of Gripper	1	0

Go to list entry: # 3

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itionFeedback
love: J1 60, J2 120, Roll 150, Stroke 800, GState 1
view: J1 60, J2 120, Roll 150, Stroke 800, GState 1
view: J1 60, J2 120, Roll 150, Stroke 811, GState 1
view: J1 60, J2 120, Roll 150, Stroke 811, GState 1
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Figure 1. The graphical user interface of the virtual robotic laboratory platform

influenced the field of telerobotics where research has shown considerable progress, with new concepts proposed and demonstrated with success, such as “predictive displays” [7], “shared-autonomy” teleoperation control [8], or the “hidden-robot” concept [9].

(b) From an *educational point of view*, teaching robot manipulation principles involves the familiarization with a variety of mechanical and control engineering concepts and skills. We aim to evaluate, mainly from a pedagogical perspective, to which extent virtual laboratory scenarios can be effectively implemented in practice and used by students to obtain practical training as a supplement to theoretical courses.

As we have already mentioned before, an effective instruction based on SLeaD should improve learning and empower students with strong learning skills and techniques suitable for engineers. Another point to be emphasized is the type of evaluation that could be used. A literature review shows that the majority of the research results in this direction are restricted either in a qualitative type evaluation or in a “usability-oriented„ approach. On the contrary, we prefer to give emphasis on the learning/didactical perspective in our evaluation approach, based on specific experimental protocols, combining qualitative and quantitative metrics; such an evaluation will give important information about the level of learning attainments of students and skills acquired during their training in laboratory training platforms.

III. VIRTUAL AND REMOTE LABORATORY PLATFORM

The virtual robotic laboratory platform is developed based on Java technologies. The graphical user interface (GUI) integrates the following panels (see Fig. 1):

- *2D graphical representation* panels (top-view and side view), visualizing both actual and commanded robot configurations,
- a *real-time video streaming* panel, which is based on RTP and implemented using JMF, showing (when on-line) the real remote manipulator in motion,
- a *control/command editing* panel,
- an interactive panel providing an exact emulation of the robot’s Teach Pendant, called *Virtual Pendant*,
- *status and feedback* panels providing real-time textual information on current robot state, and
- a *virtual robot* panel, implemented using Java3D API, providing 3D visualization of both the commanded (preview animation) and the current robot configuration.

The remote laboratory platform is based on a *client-server architecture*, enabling users to connect via Internet (or LAN). Figure 2 shows the overall architecture of the platform, which supports multiple connected users through the implementation of a specific protocol using TCP/IP sockets for communication and real-time data exchange with the "robot server", described more in detail in previous work [10].

The robot server supports the following three remote control modes: (i) *direct teleoperation* control, (ii) *indirect control*, for robot *teleprogramming* via the command/editing panel, and (iii) *manual control*, that is, robot manipulator programming using the *Virtual Pendant* functionalities. These control modes are inspired from the telerobotics field, and particularly from work proposing various "shared-autonomy" and "supervisory" remote control modalities. In direct teleoperation, every command issued by the user (human operator) locally, i.e. within the GUI (master control site), is immediately transferred for

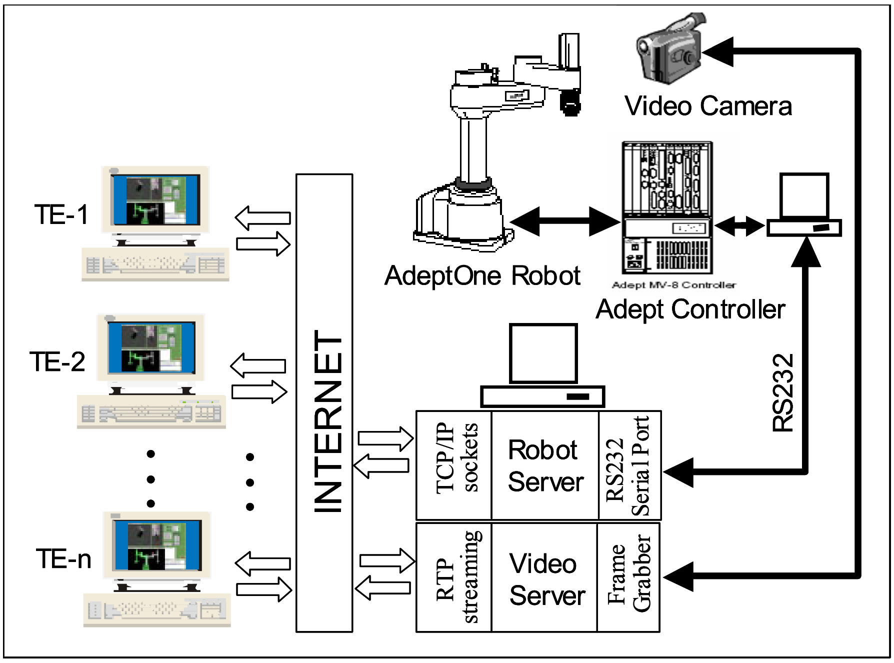

Figure 2. Overall Architecture of the Virtual and Remote Robot Laboratory Platform

execution to the remote (slave) robot. At the same time two types of feedback displays are active: (a) a *predictive display* (both in the 2D and 3D graphical panel) immediately visualising the commanded robot motion according to the human operator issued commands, and (b) a *real robot feedback display* (also both in 2D and 3D animation), showing where the robot actually is (that is, visualising current remote robot configuration, information provided in real-time through continuous feedback from the remote site).

As opposed to direct teleoperation, in the indirect "teleprogramming" control mode the commands are generated off-line, queued in a list and submitted to the robot in a subsequent time frame, when the human operator decides to do so. The idea is to be able to create a complete robot program off-line, test its validity and optimality, before actually sending the command sequences for execution by the real robot. Based on the functionality (robot command editing routines, waypoints list creation etc.) of this indirect teleprogramming mode, we have developed a third "manual-control" mode, which implements exactly the *Virtual Pendant* robot-programming scheme. According to our distance training objectives outlined in the previous section, the *Virtual Pendant* panel supports all the main functions of the real robot's pendant tool, and enables the student to learn and practice robot-programming routines locally. The user can create a robot program, add, edit or delete intermediate robot positions, as happens with the real robot's programming interface, and "preview" the programmed robot motion visually on the 2D graphical representation panels of the interface, where an animation of the predicted motion is displayed.

Two options are then offered by the system.

- In the first prototype version of the remote laboratory platform, the user could actually "transmit" the program for execution on the real, remotely located, robot, and see the results of the actual manipulator motion on the video streaming panel (as well as on the 2D graphical panels that provide continuous position feedback to the user).
- To explicitly incorporate the "virtual laboratory dimension" in the evaluation experiments, and add a third user group (group-III: virtual) for comparative performance evaluation and assessment purposes, a second option is provided to the user: that of performing a "virtual submit" of the created robot program, limited only on the virtual robot that provides a kinematic simulation and 3D visualization of what the real robot would do, but in this case with no real remote robot connected on the loop (and thus no actual video feedback from any real remotely located robot). This adds explicitly a "local virtual training mode" to the system; our goal is to evaluate this training modality in comparison with the "remote" training scheme described before, with respect to skill acquisition performance, and always in relation to the learning performance obtained when students are provided a hands-on training on a real robot.

IV. EXPERIMENTAL EVALUATION: METHODOLOGY AND INITIAL RESULTS

Firstly, we have conducted an initial pilot study on the first prototype version of the system (not incorporating yet the 3D "virtual robot" panel) to validate the usability of the system and in particular to assess its performance in terms of providing adequate "distance training" (regarding robot programming skills) to the students. In accordance with our objectives described before, the key issue on which our research focused was the evaluation of the efficacy of the proposed remote robotic laboratory scenario (in this case, programming of robot manipulation tasks). Our goal was to explore to which extent such distance training modalities can be efficiently implemented in practice, and used by students to obtain practical training as a supplement to a theoretical course track/module (in our case, an introductory course on robot manipulation).

A. Pilot Study and Assessment Methodology

We have designed a special *experimental evaluation protocol*, which was used consistently throughout the experimental process. Each group was subdivided in five teams of three to five students. The total number of the sample of this pilot study was 40 (N) students. According to this protocol, the students participating in a laboratory training course (that complements a theoretical introductory course on robot kinematics, path-planning and control) were divided in two main groups: *group-I* (real/local) trained the "classical way" on the real robot, while *group-II* (remote) was trained on the initial version of the user interface, using the remote laboratory platform as described briefly above. Both groups of students had attended the same training phases and were exposed to exactly the same educational material by the trainer during each experimental session, with the only difference between the two groups being the direct contact (physical presence), or lack of it, with the real robot on-site. Both student groups completed their training session by conducting a specific experimental evaluation test on the real robot, where a robot programming task was assigned to them (namely, programming a pick-and-place operation using the real robot teaching pendant).

Each training session lasted approximately one hour and a half, with the tutor (always physically present) explaining all key issues to the students. Tutorial and educational support material was provided to the students describing: (i) the robot used in the experiment (its mechanical and kinematic characteristics, as well as its control and programming features) and (ii) the exact procedure and steps to follow to program a robot manipulation task using the pendant. During each training session, two simple tests were performed by the students to assess their learning progress and the needs for further tutoring, as well as to motivate students' initiative in specific problem solving situations. These intermediate tests also aimed to track differences in the learning curve between the two groups (group-I trained locally on the real robot, and group-II trained on the interface remotely). In the sequel, group-I is usually referred to as the "local„ group, and group-II is referred to as the "remote„ one.

By the end of each training session, students belonging to both groups completed their training by performing a specific experimental evaluation test on the real robot (test-3, *final test*). During this final test, a robot-programming task was assigned to the students (namely, a *pick-and-place operation* using the real robot teach-pendant). It must be emphasized here that this final assessment test was performed on the real robot for both student groups (meaning that group-II students had to move from the remote location –separate building– to the real robot laboratory site to perform final assessment tests). The test was sub-divided into distinct time phases, to facilitate tracking the performance of the students and identifying errors committed and/or difficulties encountered. In order to assess students' performance, a *scoring chart* was used by the trainer during the experiment, as mentioned in the previous section, and the errors were classified according to three main categories: low-level technical skills, mid-level skills, and higher-level understanding, with different weights assigned to them.

The method used to consistently grade students' performance consisted of assigning a pre-specified "penalty grade" for each specific error committed. Errors could belong to one of the three main categories mentioned above, and could for instance range from simply pressing the wrong button (or forgetting which button performs a specific function, and referring to the manual, in which case a penalty grade = 2 points was added to the "low-level" category) to higher-level mistakes or misconceptions, expressed by an incapacity to create and implement a correct plan –sequence of actions– for programming a robot subtask (penalty grade = 5 points added to the "higher-level" category; in case tutor intervention was asked, an extra 5 points were added to the penalty score in the respective category). Moreover, teamwork between students (performing the experimental session in groups of 3-5 individuals) was qualitatively monitored, while total time needed to complete each phase of the test was also recorded. All these scoring items (indicating the frequency of the different types of mistakes) were coded in real-time on the scoring chart by the tutor monitoring the experiment, and were subsequently decoded to compute the final values for the different scores. For each final assessment test, a total score was computed giving a global measure of performance for the respective team of students, while individual categories scores give an idea of the type of difficulties encountered by the students.

The test was sub-divided into distinct time phases, to facilitate tracking the performance of the students and identifying errors committed and/or difficulties encountered. Intermediate tests were also conducted (on the real robot or remotely using the telerobotic interface and the virtual pendant), in order to track differences in the learning curve between the two groups.

B. Initial Results and Discussion

In the first pilot study, based on the scoring chart and the associated penalty grades, a t-test of independent groups was followed in order to find out whether there exists statistically significant difference between the Means of the various test scores (low, mid, high, time and total) for the two groups (group-I: local and group-II: remote); group was the independent variable and score values were the dependent. Initial results obtained are shown in Table I, which includes Means and Standard Deviations of the final assessment test (test-3) scores for Group I (real/local) and Group II (remote); these scores refer to the three different categories (low, mid, high), to the total time needed by students to accomplish the assessment task, and to a total score. The mean values of these scores for both groups are also illustrated as a bar graph in Figure 3.

A preliminary analysis of these initial results shows that there exist some apparent differences between the two groups for the three different score categories. Indeed, in the "low" category (representing errors committed related to low-level technical skills) group I (local) students made fewer mistakes compared to students of group II (remote). This could be explained by the fact that students forming the "local" group were trained the traditional way on-site, in physical contact with the real robot manipulator system, as opposed to group-II students who were trained remotely using the graphical user interface. Therefore, as it could be expected, group-I students exhibit a better "visual memorisation" of low-level technical dexterities, and thus better performance in the manipulation of the

TABLE I.
MEANS AND STANDARD DEVIATIONS OF THE FINAL ASSESSEMENT TEST
(TEST-3) SCORES FOR THE TWO GROUPS (I: LOCAL AND II: REMOTE)

	Low	Mid	High	Time	Total Score
Group-I Mean	1.80	3.40	1.80	18.8	25.8
Group-I STD	1.92	3.13	2.49	4.71	6.98
Group-II Mean	5.80	2.40	1.60	20.2	30.0
Group-II STD	3.83	1.95	0.55	1.48	5.83

robot's teach pendant. This is not the case for the mid- and high-level category skills, where the local group (group I) exhibited higher scores compared with the remote group (group II) (though differences proved to be smaller). This could be partially explained by the fact that students trained on a virtual environment appeared to have a better concentration and motivation level (as compared with students of the "local" group), which apparently aided them to assimilate higher-level concepts to a better extent.

Based on the scoring chart and the associated penalty grades, a quantitative analysis followed by means of specific statistical techniques; for this reason we used S.P.S.S., version 12, to obtain statistical analysis results. More particularly, a t-test of independent groups was followed, and results of this first pilot study are shown in Table II. According to these initial results, no statistical significance was found ($p<0.05$) between the two groups in the final assessment's test scores (low: value t= -2.085, p=0.071; mid: value t= -0.606, p=0.561; high: value t= 0.175, p=0.865; total score: value t=-1.033). This means in fact that the performance of both student groups is similar in terms of the scores obtained in the final assessment test. In other words, all student teams from both groups (local/traditional and remote/experimental) performed equally well in statistical terms, with no significant deviations observed that can be attributed to the different type of training of each group (besides the minor differences discussed above).

Based on all these quantitative results obtained during this first pilot study –both for the low and mid/high categories, as well as also for the total time and average score values– statistical analysis (t-test) thus reveals that all aforementioned differences in students' performance are *non statistically significant*. Therefore, one can conclude that the remote laboratory platform, with its graphical user interface, creates indeed a virtual training environment, which on its whole (integrating the various interactive control and visualisation panels) provides adequate learning elements, as related to mid and high level skills, compensating for the lack of direct physical presence on the real robot site. means that a remote laboratory platform, such as the one developed and implemented in this first pilot study, can be integrated effectively and efficiently in the practical training of students.

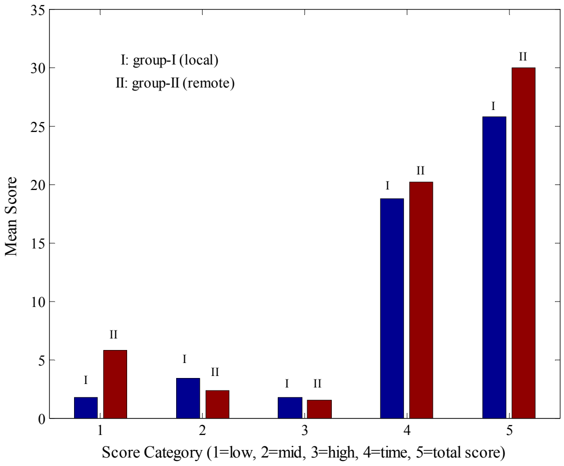

Figure 3. Mean Scores of the two Groups in the Final Assessment Test

In the second pilot study, which is currently under way, we are trying to extend the scope of our study focusing on exploring the differences both for the low and mid/high categories, as well as also for the total time and average score values, for three different student sub-groups: (a) the "classical" (local/real robot) group, (b) the "remote" group (without no 3D virtual), and (c) a third "virtual" group (with no actual remote robot on the loop). In this direction, a series of questions arise, amongst which are the following ones: (i) in which group, the learning process has a better impact on students' acquired skills? (ii) Are the learning skills acquired at a higher degree when there is a virtual training mode active, instead of a remote one? (iii) Which are the learning outcomes in a case study combining the virtual way of training in conjunction also with a remote training mode? Such a comprehensive evaluation between real, virtual and distant laboratory experimentation remains our primary future research direction in this framework, aiming to contribute towards a more profound understanding of the theoretical pedagogical basis of different laboratory experiences.

V. CONCLUSION

We have described the development and experimental evaluation of a "virtual and remote laboratory platform" in the field of robotics. The system in its current configuration is designed to enable remote and/or virtual training of students in real scenarios of robot manipulator programming. Our research efforts focus on the adaptation of concepts and technologies developed in the field of telerobotics and virtual reality, and on exploring their implementation in such remote laboratory settings. The

TABLE II.
T-TEST FOR THE TWO GROUPS IN THE FINAL ASSESSMENT TEST
(STATISTICAL SIGNIFICANCE, P<0.05)

	t	P
Low	-2.085	0.071
Mid	0.606	0.561
High	0.175	0.865
Total score	-1.033	0.332

experimental platform was developed based on Java technologies. The graphical user interface incorporates, among other features, a “Virtual Pendant” panel providing an exact emulation of the real robot’s Teach Pendant functionality. The learning aim is to offer students the possibility to learn how to program a real robot without having one at proximity, in such a way that closely resembles the real robot programming operations and procedures.

A first pilot experimental study was conducted to evaluate system performance in remotely training students to program robot manipulation tasks. In our evaluation approach, emphasis is given on the didactical perspective of the system, based on specific experimental protocols combining qualitative and quantitative metrics. We aim to assess the effectiveness of these new media compared with traditional hands-on laboratory training scenarios. The experiments were conducted according to a specially designed evaluation protocol, using scoring charts to assess performance of the student groups participating in the laboratory-training course. Statistical analysis (t-test) of independent groups was performed to find out whether there exists statistically significant difference between the means of the various performance scores obtained for two student groups: group-I (local) trained the traditional way on the real robot, and group-II (experimental) trained using the remote laboratory platform. The results of the first pilot study are encouraging enough, showing that despite some apparent differences mainly for the score category regarding low-level technical skill transfer, no statistically significant differences exist between the two student groups. Thus, the main experimental result can be summarized by the following statement: the proposed remote laboratory platform created a virtual training environment, which provided adequate learning elements, as related particularly to mid and high level skill transfer, compensating for the lack of direct physical presence on the real robot site.

We insist here on the fact that the results presented in this paper provide conclusions about performance comparison between the different student groups participating in the specific pilot study context analyzed above. Despite the fact that we certainly do not assert that these initial results lead to a general conclusion about what one should definitely expect in a completely different didactical context (as this would require a larger-scale sample and experimental procedure, which remains one of our key future work priorities), we do believe however that these results are helpful and insightful, indicating that such remote laboratory platforms can indeed be implemented quite efficiently and effectively.

We are currently investigating ways to extend the scope of this study by incorporating a third group, group-III (virtual) also trained on the user interface, but using only the "virtual robot" functionalities of the platform with no remote real robot connection on the loop. Such a comprehensive evaluation between real, virtual and distant laboratory experimentation remains our primary future research direction in this framework, aiming to contribute towards a more profound understanding of the theoretical pedagogical basis of different laboratory experiences. Initial results are showing the need and the benefits associated with the development of real training scenarios in the frame of remote laboratory education aiming to achieve effective learning schemes for students in the engineering field. Another key issue that would then remain to be emphasized and clarified in the future concerns the long-term deployment of such educational schemes (in a "lab-facilities sharing" context) and the associated benefits that can result from such implementations.

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