Development and Experimental Evaluation of a Remote Laboratory Platform for Teaching Robot Manipulator Programming

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Extended Abstract

In this paper we describe the development, design and structure of a remote laboratory platform for teaching robot manipulator programming skills. Also, emphasis is given on the experimental/pilot-study evaluation of this virtual laboratory platform, based on the construction of a special evaluation protocol.

The user interface is based on Java technologies and incorporates mainly: (a) 2D graphical representation (top-view and side view) panels, visualizing both actual and commanded/ robot configurations, (b) 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, and (c) an interactive panel providing an exact emulation of the robot's Teach Pendant, called *Virtual Pendant*. The Virtual Pendant provides all the main functions of the real robot's programming interface, 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. He can then either "preview" the robot program visually on the 2D graphical representation panels of the interface, where an animation of the predicted robot motion is displayed, or "send" the program for remote execution on the real 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).

This remote laboratory platform is based on a telerobotic client-server architecture, providing to the human operator support for both direct (teleoperation) and indirect (teleprogramming) control modes. The latter provides the functionality needed for the implementation of the Virtual Pendant off-line robot-programming scheme, outlined above. Moreover, the system supports multiple users connected via Internet (or LAN) using TCP/IP sockets for communication and real-time data exchange. Each client (student) can connect to the robot server either as an "observer", or as an "administrator", in which case (after entering the correct password) actual control of the real robot is obtained. The robot used in the experiments is a SCARA-type Adept I manipulator with 4 degrees of freedom.

We have conducted a set of evaluation experiments with the system to validate its usability and in particular to assess its performance in terms of providing adequate "distance training" to the students regarding robot programming skills. According to the experimental evaluation protocol used consistently throughout the experiments, the students participating in a laboratory training course (that complements a theoretical introductory course on robot kinematics, path-planning and

Submitted to: International Conference on Engineering Education 2004, (ICEE 2004), October 16-21, 2004, Florida, USA

control) were divided in two main groups: group-I trained the "classical way" on the real robot, while group-II was trained on the user interface, using the remote laboratory platform as described briefly above. Both groups of students had undergone 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). 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. A scoring chart was used by the trainer during the experiment, and the errors were classified according to three main categories, namely: low-level technical skills, mid-level skills, and higher-level understanding, with different weights assigned to them. Teamwork between students (performing the experimental session in groups of 3-5 individuals) was also qualitatively monitored. Analysis of the initial experimental results (both qualitative and quantitative through statistical analysis of variance) is quite encouraging showing that performance between the two student groups is comparative, with a slight decrease for group-II regarding mainly low-level technical skill transfer in the initial phases of the final evaluation test of each experimental session.

In the near future we are looking forward to conducting a more thorough experimental evaluation study regarding: (a) the usability of the graphical user interface, in order to improve its design from an ergonomic point of view, and (b) the educational impact of the remote laboratory system, including also teaching robot programming with the V+ programming language. Furthermore, the implementation and integration of a virtual (3D graphics) robot panel, based on Java3D API, which is currently under development, is aiming to ameliorate the realism of the simulation in an off-line self-education mode, as well as the motion preview and real tele-monitoring capabilities of the system, which can increase both its user-friendliness and educational impact upon students.