ED I:
NYU Educational Robot

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Abstract

The primary goal of the NYU educational robot project is to create a disseminable, multi-functional and inexpensive laboratory course sequence, aimed at improving the practical skills of undergraduate students specializing in robotics, vision, AI and manufacturing disciplines.

The main work-horse of the NYU educational project was chosen to be a multi-functional ED I robot system, consisting of a 4 DOF DD arm and several auxiliary devices. The system was designed to be simple, inexpensive, flexible and safe.

In this report, we describe the history, design, structure and evaluation of this robot system. We also describe several robotics and related course sequence that can use the ED I system effectively. We also provide some example experiments that have been run on ED I successfully.

This report has benefited from the labor, contribution, discussions, advice and criticisms of several people on the ED I project team and the credit for the final product goes to the entire team.

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1. Introduction

1.1 Initial Goal

In the spring of 1990, we initiated an educational project at NYU, whose primary goal was to create a disseminable, multi-functional[1] and inexpensive laboratory course sequence, aimed at improving the practical skills of undergraduate students specializing in robotics, vision, AI and manufacturing disciplines.

Our motivation to build such a laboratory arose primarily from our desire to provide students with the practical experience to complement their understanding of the principles involved in robotics, automation, AI and manufacturing sciences. In the past, most of the research in robotics was motivated by simple applications using industrial robot arms suitable for routine welding, spray-painting and part-assembly operations. At the time we initiated this project, there were few universities with regular robotics courses aimed at undergraduates; where a standard introductory course existed, students typically regarded a robot as an open kinematic chain, having a straightforward kinematic and dynamic structure. The accompanying laboratory training typically involved only the programming of a commercial industrial robot to perform simple 'pick-and-place' tasks.

Thus, we felt that there was an acute need for robots suitable for the more extensive educational purpose. To achieve this goal, we proposed to build an 'educational robot' with a structure, which is simple and yet easily modifiable for the multiple functions it may have to serve.

We have designed and built a 4-DOF direct-drive arm, ED I, which can be easily augmented with tactile and force sensors as well as manufacturing tools, and which can be controlled from a simple computer system. This robotic system has been successfully used in two introductory robotics courses (one undergraduate, the other graduate), a CAD/CAM course and to some extent, in a vision course.

In this document, we shall describe the robot and our experience with the undergraduate course taught by B. Mishra and R. Even (teaching assistant).

1.2 The Role of ED I Robot

The ED I robot plays a key role in the entire project. Thus much thoughts and efforts went into careful design, periodic evaluation and modification, and augmentation of the functionalities of the ED I robot system.

The final design was chosen to incorporate direct drive technology in order to keep the system modeling and control simple. The actuators were chosen to be rather powerful so that if necessary they can be used at their full power; for the normal experiments they were used at a lower power level with a smaller gain. As the system was planned to be used for certain manufacturing applications, the robot was designed to operate with a high level of accuracy. Finally, as the system was to be used by novice users, it was assumed that the system will be used occasionally in inappropriate manners and precautions were taken to improve the safety of the system at various levels. As the ED I robot began to be used by the students, the design-team monitored the students usage and rectified any flaw—especially, in the system safety—that became apparent.

In order to make the system multifunctional, the design of the system (particularly, workspace, payload limits, kinematics and dynamics) was kept extremely simple and flexible. The ultimate

[1] The proposed laboratory is multi-functional in the sense that the same laboratory may be used for more than one area: AI, vision, robotics, real-time systems, manufacturing, for instance.

design can be augmented by machine tools, x-y table with pan/tilt, vision system, various sensory tools etc. The amount of time required to switch from one configuration appropriate for one course to another configuration for quite a different course was constrained to be a matter of less than couple of hours. Thus, in principle, the same system can be used by two different courses running in parallel.

Figure 1: **NYU Undergraduate Teaching Laboratory. ED I, in the background, is being operated by an experimenter.**

1.3 History

The construction of the laboratory was started in 1990 with a team consisting of Z. Li, A. Cen (an electronic engineer), J. Li (a mechanical engineer), C. Li, N. Silver (graduate students) and L. Gurvits (a control theory researcher). A first course was taught with existing IBM SCARA robots. The first educational robot was completed by the end of 1991. The first evaluation of the laboratory was made in the summer of 1992. A new team was created to redesign the laboratory; the new team was headed by Bud Mishra and also included Fred Hansen (an experienced engineer) and Louis Pavlakos (a software engineer).

• **Courses:** A series of robotics related courses using the laboratory have been successfully taught at NYU. The courses include: Introduction to Robotics (twice), Advanced Robotics, CAD/CAM and Computer Vision. The first-level robotics course has been accepted by the university as a regular course for the computer science major and is now listed as a 4 credit course in the university handbook. The maturity and the preparation of the students in these courses have varied over a wide range: high school students (from Dalton School), engineering students (from Stevens Institute of Technology) and computer and mathematics students (largely from New York University). Some undergraduate students have also used the lab facilities to carry out independent study programs and projects.

• **Evaluation:** The first implementation of the robot was evaluated by a team headed by Bud Mishra and Israel Greenfeld (currently a research engineer in Israel). The precision provided by the robot as well as various safety measures were considered severely lacking. The software structure was deemed not easily portable. A completely new hardware and software design was made. The implementation of the new system was started in July 1992 and a first implementation was completed by mid September.

In order to improve the precision (specially for CAD/CAM experiments), the z axis was completely redesigned and reimplemented. The other two main links were remachined to rectify certain design errors. The hardware safety was improved by running the motors at lower power levels; incorporating shock absorbers, limit switches and by enclosing the entire assembly by a lexan enclosure. The motor controllers were redesigned using Phoenix and Creonics boards, which are capable of stopping the robot (and eventually shutting the power off) in case of a serious exceptional situation. A manual emergency "red" button has been made available for the teaching assistant in order that a potentially dangerous situation could be averted.

The software was redesigned under the "MOSAIC" system (developed independently by the NYU manufacturing group[11]) and on top of `VxWorks`tm real time systems. The MOSAIC system has been recognized by and gained acceptance in the manufacturing community as a leading control software system. By founding on a well-tested system, we could improve the system reliability and the development time considerably. However, if there is a need, the MOSAIC/`VxWorks`tm system can be easily interchanged with another real time system.

1.4 The Organization of the Report

The report is organized as follows: In Sections 2 and 3, we describe the hardware and the software architecture of ED I, respectively. In Section 4, we discuss primarily the undergraduate "Introduction to Robotics" course (taught by B. Mishra and R. Even), and list the experiments conducted with ED I, in the context of this undergraduate course. This section by itself may be of interest to other instructors who may want to adapt these experiments to a different robot system. Section 5 describes the safety measures taken with respect to ED I and finally, Section 6 concludes the report with some thoughts on our contributions and on the future of robotics education. We have also provided two appendices: one containing some example programs for and operation of the ED I robot, and the other containing a description of a sequence of courses, where ED I has already been used or is planned to be used.