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A PROGRAM FOR TEACHING THE FUNDAMENTALS OF ROBOT MODELLING AND CONTROL

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Abstract. The paper presents a program for robotics education that runs on standard IMB-PC's under the Microsoft Windows environment. The program WinRob is designed for undergraduate students and emphasises the aspect of robot modelling. The software is self-explanatory and uses menus, dialog boxes with figures and context-dependent on-line help. In this perspective, students are motivated to investigate on the kinematics, dynamics, trajectory planning and control in order to get insight into robotics.

Key Words. Robots; manipulators; software; modelling; education; control systems

1. INTRODUCTION

In the last two decades robotics became a common subject in courses of electrical, computer, control and mechanical engineering. Progress in scientific research and developments on industrial applications lead to the appearance of educational programs on robotics covering a wide range of aspects such as kinematics and dynamics, control, programming, sensors, artificial intelligence, simulation and mechanical design. Nevertheless, courses on robotics require laboratories having sophisticated equipment which poses problems of funding and maintenance. Computer-based education is a well-established alternative that overcomes some of the referred problems. In this line of thought, university teams (Derby, 1983; Derby, 1986; Eydgahi and Sheehan, 1991; Parkin 1991; Raz, 1989; White *et al.*, 1989) and software houses (Robot3D, 1994; SYMORO, 1990; WorkSpace, 1989) developed robot simulation and programming packages running on Apple and IBM-PC computers. Nevertheless, often, computer programs emphasise capabilities such as the 3D graphical simulation and the programming language and give a smaller importance to mathematical aspects of modelling and control. To cover this area, some researchers proposed the adoption of symbolic packages such as Mathematica and MACSYMA (Leu and Wang, 1990; Lloyd and Hayward, 1988; Nethery and Spong, 1994; Vira and Tunstel, 1992) to illustrate robot kinematics and dynamics. However, undergraduate students with no prior experience may feel difficulties in getting into the robotics experiments before overcoming the symbolic package procedures and commands. This state of affairs, motivated the development of a computer program highlighting the fundamentals of robot mechanics and control. Given the popularity of Microsoft Windows it was decided to implement the software in this environment using the Microsoft Visual Basic language. The project lead to the WinRob program which was adopted as an educational tool in a first course of robotics. This paper presents, in section two, the main aspects of the package. Future software enhancements are discussed in section three and finally, in section four, conclusions are drawn.

2. PROGRAM DESCRIPTION

The WinRob educational package was designed to take full advantage of the Windows environment. All the commands and the required parameters are entered through pull-down menus and dialog boxes. The software is intended to be self-explanatory to the extend possible to encourage students exploring the program. For the same purpose, help menus are also available throughout the different windows. Several dialog boxes include figures to clarify context-dependent definitions. Experiments are restricted to two dof (i.e. planar) manipulators. This strategy intends to decrement the 'weight' of the graphical simulation and to give importance to the mathematical aspects of kinematics, dynamics and control while maintaining the program at an introductory level. Moreover, this option allows the use of inexpensive PC's because of the low computational requirements. On the other hand, numerical data files and graphical data files have formats compatible with other Windows applications to allow data interchange and external data calculation. As usual in Windows programs the top of the screen contains the main menu bar. The top menu bar includes the entries: File, Edit, Model, Tools, Control, Programming and Help. Figure 1 shows the selections available on each menu.

In order to demonstrate the capabilities of the package the paper shall now follow a typical classroom session. The tour begins with the definition of the type of robot within three possibilities: the PP, RP and RR planar structures (R-Rotational, P-Prismatic). After selecting the robot type, WinRob presents a dialog box (see Fig.2) for entering the robot numerical parameters, namely the joint limits, the link lengths and masses and the actuator inertias. Later on, these numerical parameters can be viewed, changed and saved using the File and Edit menus. The second phase of the session consists on the definition of the robot trajectory. Selecting Kinematics on the Model menu the student is faced with two options: Teach and

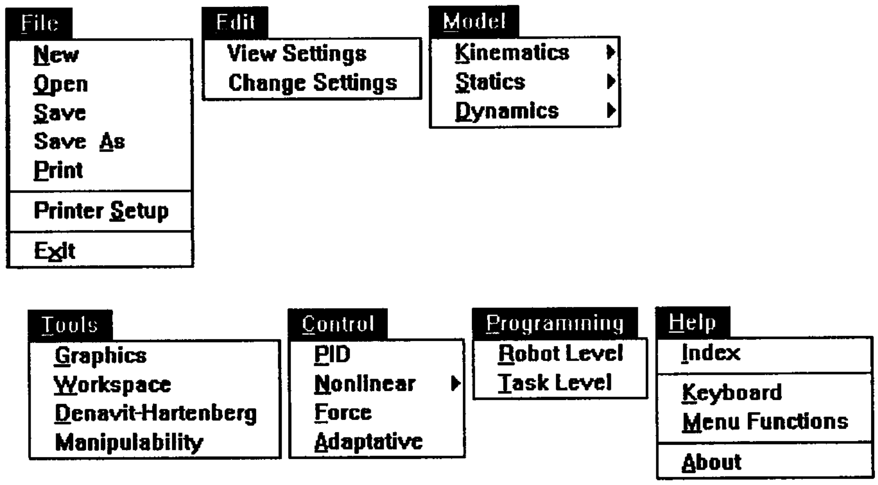

Fig. 1. Selections available in the main menu

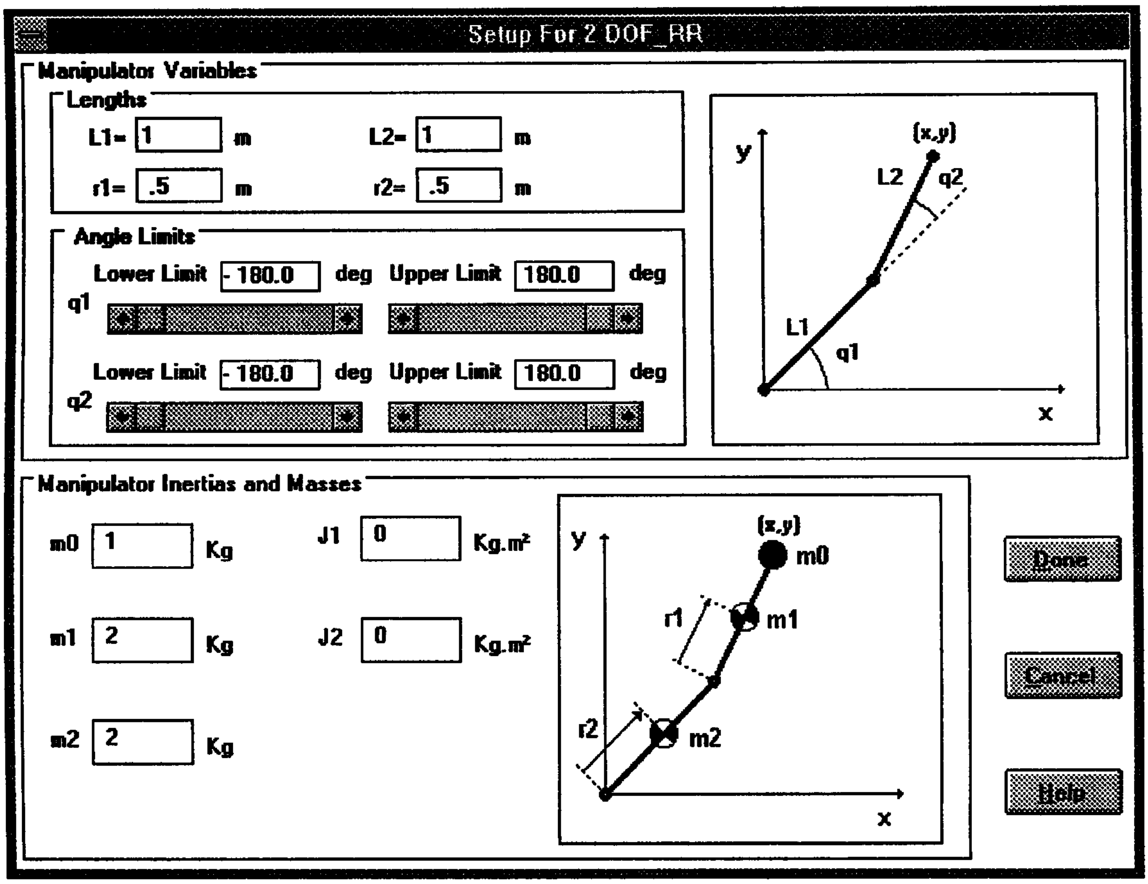

Fig. 2. Setup of the robot structure

Load. Choosing the Teach entry leads to the Pendant Form (see Fig.3) where the user can teach several points of the path (in the joint space or, alternatively, in the operational space) using the mouse or the keyboard. In all graphical forms, point coordinates and its corresponding units can be easily known pointing with the mouse.

entries Statics and Dynamics in the menu Model become available. The Statics allows the Teach and Load options while in the entry Dynamics we can have the Inverse Dynamics and Direct Dynamics. The amplitude *versus* time evolution of the forces at the robot hand can be teached as a piecewise linear function approximation whose points are

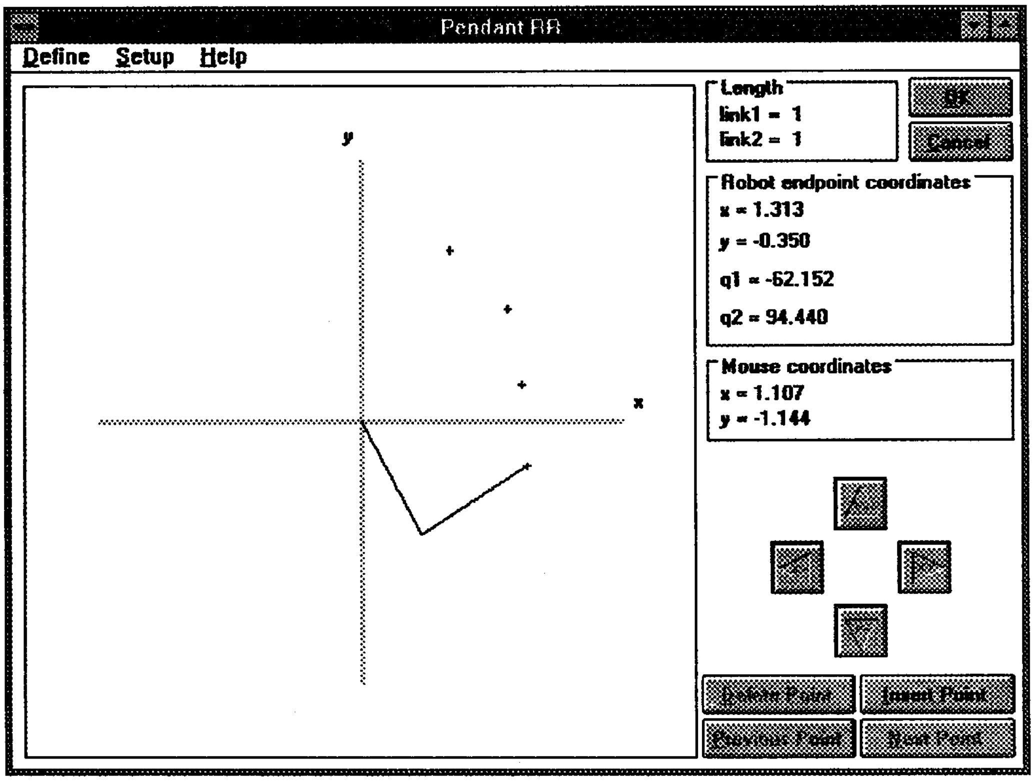

Fig. 3. Teaching trajectory points

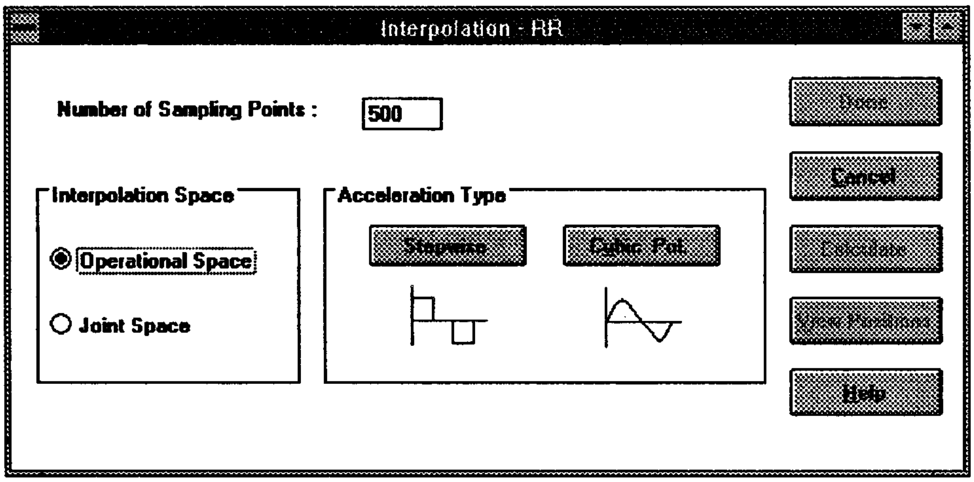

Fig. 4. Definition of the trajectory interpolation

To complete the trajectory definition the program depicts the Interpolation Form (see Fig.4) for the selection of the interpolation space, the number of interpolation points and the Acceleration Form (see Fig.5) for the time evolution of positions, velocities and accelerations. After defining the trajectory, the inserted/deleted through the mouse (see Fig. 6). The third phase of the lesson consists on selecting Graphics on the Tools menu. In this case, we can view (see Fig.7) the evolution (in the time and phase plane domains) of the variables.

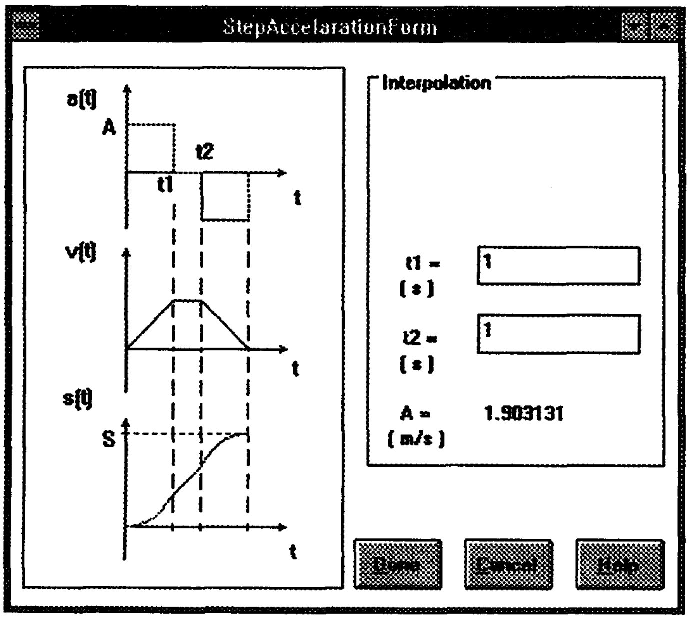

Fig. 5. Definition of the time evolution of the variables

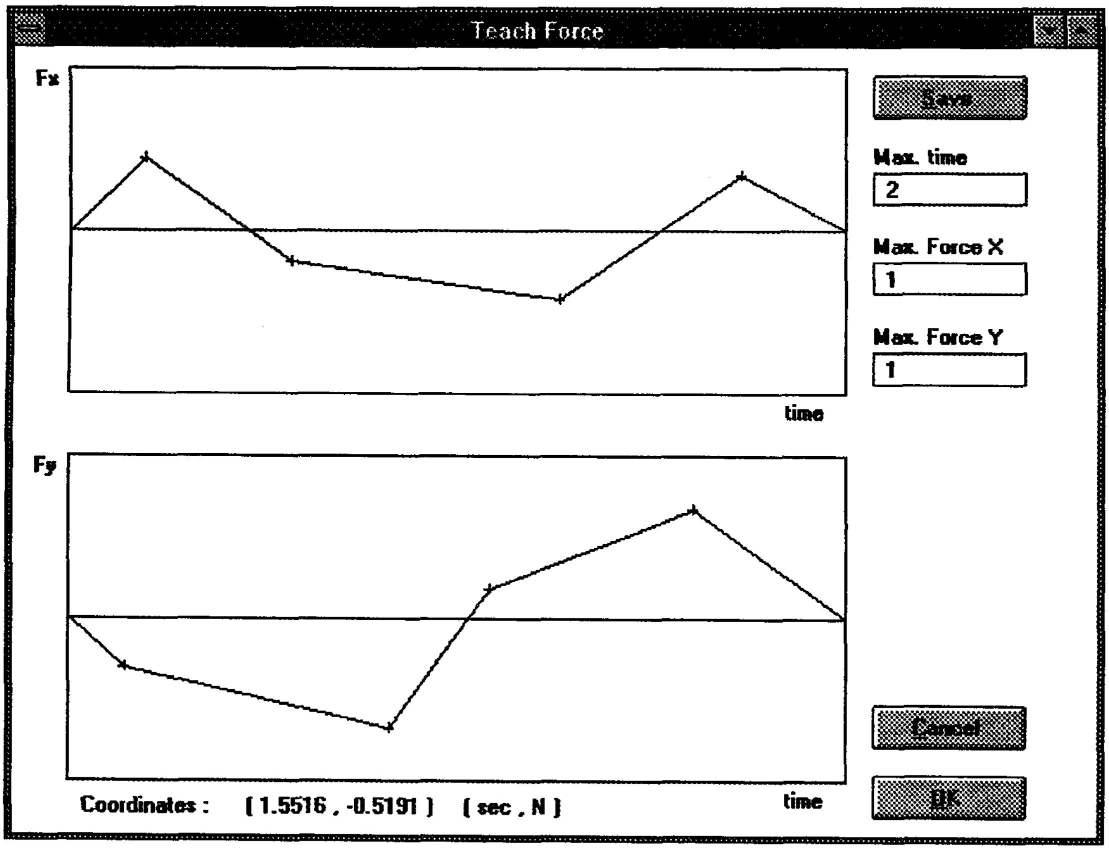

Fig. 6. Teaching static forces

The Tools menu includes other entries such as Workspace and Manipulability (see Fig.8) for the analysis of the robot properties. The Denavit-Hartenberg entry was designed as a 'customized calculator'. In this sense, the student can enter numerical values and view the corresponding robot configuration. The menus Control and Programming are still under development. Figure 9 shows the form for the PID controller definition. The student must define the gains in the continuous or the discrete domains as well as the frequency of the digital controller.

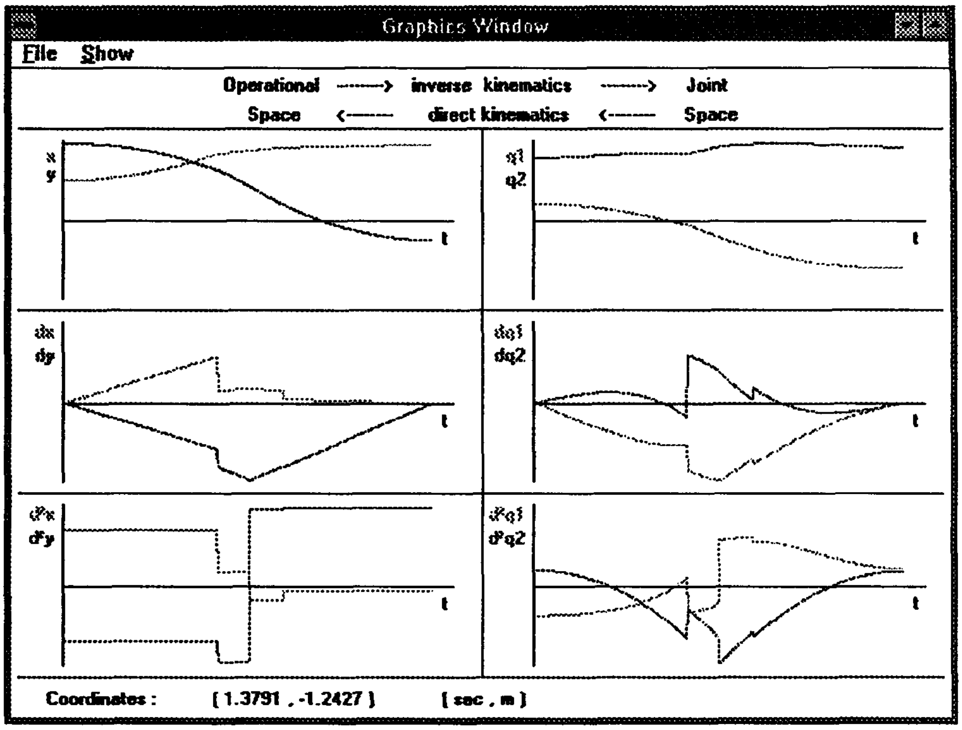

Fig. 7. Time evolution of the positions, velocities and accelerations in the operational and joint spaces

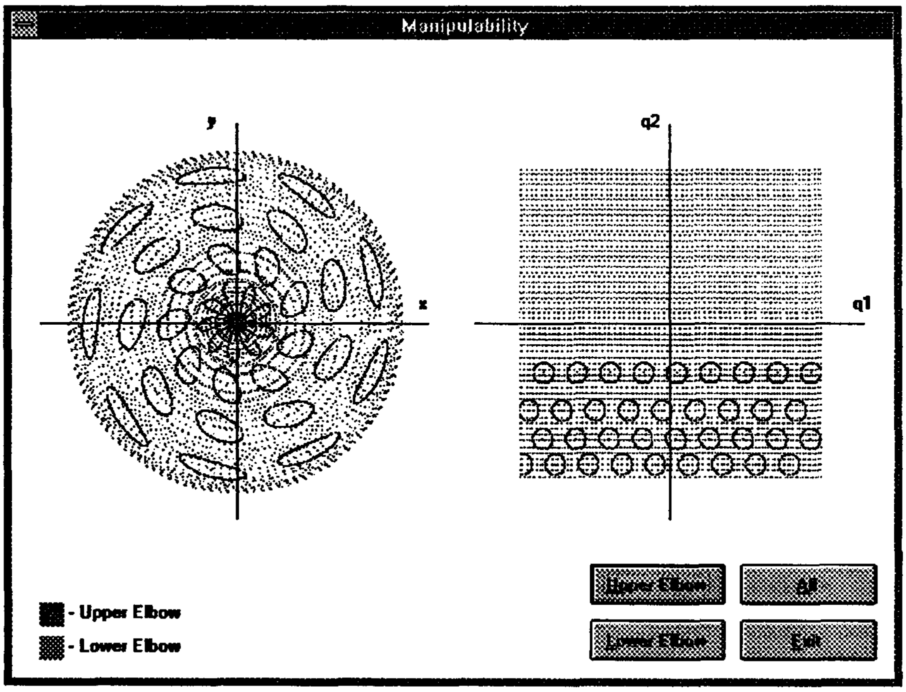

Fig. 8. Robot manipulability

3. FUTURE SOFTWARE ENHANCEMENTS

WinRob is planned to include several additional educational features. In the robot definition, selection on structures such as counterweights and parallelogram linkages will allow the study of compensation schemes leading to a new dynamics (Machado *et al.*, 1993). The Tools menu will include an entry for the analysis of different methods of calculation of the inverse dynamics (Machado and Galhano., 1994). In this perspective, the student can investigate alternative methods such as the Lagrange-Euler and the Newton-Euler numerical recursive algorithms (Hollerbach, 1980; Luh *et al.*, 1980) and the adoption of symbolic formulae (Neuman and Murray, 1987).

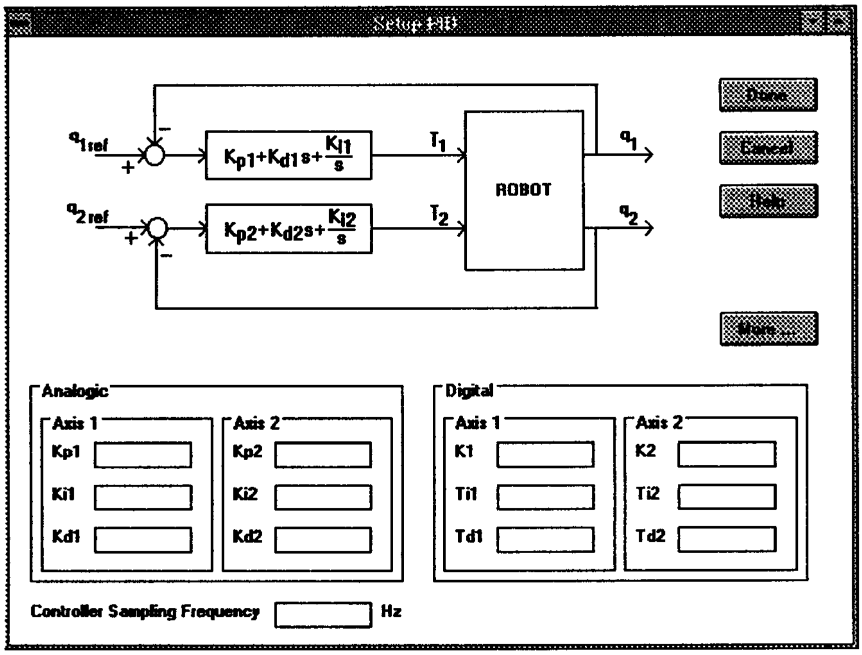

Fig. 9. Setup form of the PID controller

4. CONCLUSIONS

A program for robotics education has been presented. WinRob is a package that runs on standard IMB-PC's under the Microsoft Windows environment. The program is designed to be used at an introductory level for undergraduate students and emphasises the aspect of robot mathematical modelling. The software is self-explanatory and uses menus, dialog boxes with figures and context-dependent on-line help. In this perspective, students are motivated to investigate on the kinematics, dynamics, trajectory planning and control in order to get insight in robotics, before getting into expensive laboratory experiments with real robots.

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