EXPLORATIONS IN DESIGNING MECHANISMS AND PROGRAMMING SPATIAL MOVEMENTS USING RASCAL

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Abstract— *This paper considers hands-on learning experiences in analysis and synthesis of mechanisms to generate various motion behaviors. The studies are conducted in a robotics environment based on the robot construction kit Rascal. The kit contains essentially all hardware and software components required for desktop construction of various robots. A number of robotic assignments are considered with regard to the complexity of desired motions and appropriate mechanical configurations. We also give examples of Rascal-based curricula developed at college and school levels.*

Index Terms ¾ Educational robotics, digital manipulatives, Rascal, mechanical design, spatial movements.

INTRODUCTION

Robots are a category of mechatronic engineering products, capable to perform functions which are normally ascribed to humans, interact with them, and act autonomously in various physical environments. Educational robotics relies on the concept of constructionism proposed by Seymour Papert [1] to characterize learning processes, in which a learner is involved in the creation of external and sharable artifacts. The learner uses artifacts as “objects to think with” in order to explore, embody, and share ideas related to the topic of inquiry. Studies show that this approach could be effectively used to educate students of all age and experience, and stimulate their intellectual maturity [2]. In the robotics course a robot is introduced as “the object to think with” and the project-based curriculum focuses on designing, building and operating autonomous robots.

Mitchel Resnick and his colleagues [3] developed a new conceptual framework of digital manipulatives which extends the traditional learning with manipulative materials. Accordingly, the computational and communications capabilities are embedded in mechanical parts of a construction kit. The students use the kit to create various devices and program their movements. The paper [3] presented programmable bricks and crickets for use with Lego kits, and called for empirical studies of how and what students learn through their interaction with digital manipulatives.

This paper presents our experiences in teaching basics of mechanical design and programming spatial movements in the conceptual framework of digital manipulatives, using a new construction kit Rascal.

THE RASCAL KIT

The Rascal set contains essentially all components required for desktop robot construction. Its mechanicals include servomotors, aluminum links, parallel-jaw wrist-and-gripper assembly, construction bases, and other parts (Figure 1).

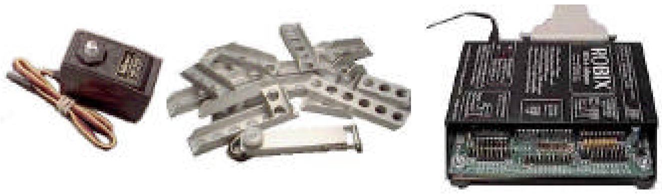

FIGURE. 1
RASCAL COMPONENTS: SERVOMOTOR, LINKS, ELECTRONIC INTERFACE

The learner uses them to build various mechanical devices driven by the servos. An electronics interface (EI) is connected to the host computer through the parallel port. It has servo outputs, on-off outputs for device control, and sensor inputs (analog-to-digital and switch-closure). EI serves to control and power servos together with sensors and other devices introduced by the learner.

The software supports a scripting language for generating point-to-point motion sequences, each move with matched velocity trapezoids and motion parameters per-servo. The user can define the positions (points) in "teach pendant" or “coordinate” modes. Scripts run by operator from console and also programmatically from C/C++, Visual Basic, or Java.

TECHNICAL COLLEGE CURRICULUM

Course Description

The Design of Computer Controlled Mechanisms course (DCCM) was given to second year students majoring in mechanics. In the DCCM course the students learned basic concepts of machinery and practice their application to

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robotics using the Rascal kit. Special attention in the course was paid to visualization of mechanisms and their movements using Autodesk Inventor™ animations. The topics included in the 30 hours course were as follows:

- Position and orientation of a rigid body.
- Mechanisms, structures, and degrees of freedom.
- Basic and composed mechanisms.
- Lever mechanisms (four-bar, slider-crank, and coulisse).
- Methods of linkage design.
- Mechanism structure analysis.

In the practical part of the course the students designed and built models of basic mechanisms, determined their work envelopes, analyzed driving-driven link dependencies of their motion, and drew the mechanisms using the computer graphics software. Then the students connected the mechanical models to a Rascal actuator module and practiced in programming their motions.

The course assessment indicated its contribution to understanding mechanisms, their analytical and physical modeling. The students were very interested in studying mechanisms in the robotics and CAD environment.

An ellipse drawer assignment

In this assignment the students were required to develop a mechanism, which draws elliptic paths. To perform the assignment, the students designed a kinematic scheme of the drawer based on the slider-crank mechanism and built a prototype presented in Figure 2A. Experiments with the prototype showed that because of constructive limitations it could draw only small segments of the entire elliptic curve. These deficiencies were overcome in the final mechanism developed by the students (see Figure 2B).

A) B)

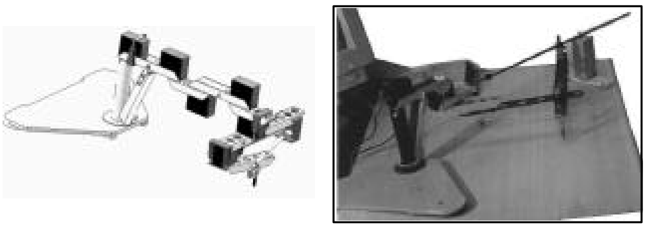

FIGURE. 2
ELLIPSE-DRAWER: A) PROTOTYPE; B) FINAL MECHANISM

The mechanism was constructed using the Rascal components, except the slider and the connecting rod. Attention was paid to increasing the crank rotation angle and guide’s length, as well as reducing tolerances in joints and slider’s frictions.

DRAWBOT: A SCHOOL GRADUATION PROJECT

This project was developed by a 12 grade student in the framework of a school graduation project (an optional matriculation subject in Israeli high-schools). It was carried out in connection with an ICT advanced-level course.

The project assignment was to develop a robot including a drawing mechanical device, an operating system to control the drawing process and graphic simulation software. The robot's task is to automatically draw geometrical objects defined by a user. The device designed by the student has two degrees of freedom and a pen, as shown in Figure 3.

FIGURE. 3
THE DRAWBOT MECHANICAL DEVICE

The operation system includes the following functions:

Direct and inverse kinematics calculations

The Rascal software provides functions of motor control in terms of pulses (rotation units). A user can manually change the mechanism's position and record its motor angle values. In the project, the user can define positions of the pen analytically by Cartesian coordinates. The operating system converts the Cartesian coordinates to motor angle values and vice versa using direct and inverse kinematics calculations. It also checks that the positions are defined within the mechanism's workspace.

Drawing algorithms

The drawings can include straight lines, basic figures and mathematical functions. A line segment is defined by its two end-points; basic figures are compositions of line segments and circles; mathematical functions are defined by analytical expressions and ranges. The drawing process is performed as follows: the system divides each of the lines to small segments, calculates the Cartesian coordinates of their end-points, converts them to motor angle values and runs point-to-point movement. Before plotting a mathematical function, the system interprets the analytical expression, converts it to a function calculation procedure and divides its range of definition to segments.

Graphic simulation

The project includes a graphic simulation of the Drawbot and the drawing process. It shows the up-view of the mechanism's scheme, the workspace and the Cartesian axes. The graphic simulation can be run in both offline and real-time modes.

This project can be used for teaching in two possible directions:

- Laboratory experiments with the Drawbot in drawing geometrical objects.
- Development of different drawing mechanisms and software similar to those in the project.

TEACHER-TRAINING COURSE PROJECTS

One of the authors of this paper conducts a course 'Teaching methods in design and manufacturing' as part of the Technion teacher training program in technology/mechanics. In the course the students learn how to guide projects through reflective practice in performing project assignments. Two examples of the projects, performed in the 2002 course using Rascal are presented below.

A Chemist Robot Project

A fast growth of automation and robotics in the chemical materials industries posed a need to introduce the subject in the science and technology education. In this connection one of our project assignments in the course was to develop a robot and a chemical laboratory environment to implement a typical experiment of preparing solutions.

The project was performed through the following stages:

- Formulating the experiment idea
  The proposed experiment related to automatic preparation of solutions of different concentration by means of a robot-manipulator.
- Selection of chemical equipment and designing a laboratory environment
  The laboratory utensils included plastic beakers, pipettes, test-tubes, and a metal holder. They were placed and fixed on a special slab.
- Designing a robot-manipulator and matching it to the environment
  This stage consisted of determining a robot workspace in the laboratory environment and developing a kinematic scheme of the manipulator.
- Building the robot and the environment
  The student built a six degrees-of-freedom manipulator, using the Rascal components, and produced a laboratory setting.
- Motion planning and programming the robotic manipulation.
  This stage included experiments in grasping, orienting, and manipulating the pipette.

The Chemist robot project prototype developed by the student is presented in Figure 4.

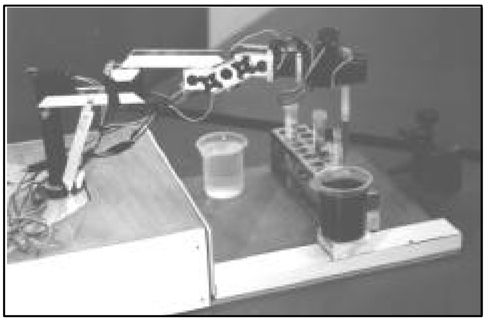

FIGURE. 4
THE CHEMIST ROBOT PROTOTYPE

A Snake Robot Project

Animal-like robots are attracting an increasing interest in biology, engineering and AI as a way to examine the general cybernetic ideas and principles of locomotion. One of the course project assignments was to develop a model imitating snake crawling motion using the components of Rascal.

The project steps were as follows:

- Movement creation
  Understanding the biological principles of crawling and their modeling.
- Kinematic scheme synthesis
  Examining alternatives and creating a Snake robot scheme.
- Mechanism analysis
  Analysis of the robot mechanism's structure, dimensions and kinematic parameters.
- Building a mechanism
  Selecting and producing parts, assembling a prototype, and its optimization.
- Programming robot crawling motion
  Modelling the motion process as a cyclic sequence of four basic movements (see Figure 5).

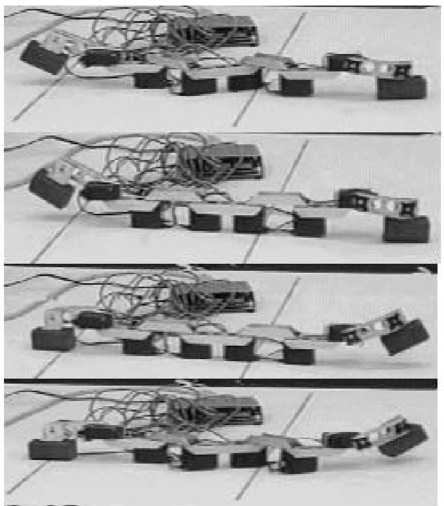

FIGURE. 5
CRAWLING MOVEMENTS OF THE SNAKE ROBOT

ROBOTICS ALA CART

The curriculum under development at Robix is called "Robotics ala Cart" ("RaC"). RaC is intended to allow student Teams of one or more students to explore major areas and issues of robotics to a depth of the Team's choosing.

Field trials of RaC are being conducted this summer (2002) at a network of for-profit, technology-oriented summer camps in the US [4]. Prior to the RaC trials, several hundred iDTC campers have used the Rascal in a more loosely structured "play-driven" manner for two summers of 2000 and 2001. Campers are of middle-school and high-school age, approximately 8 to 17 years old, and the camps themselves are held at hosting Universities around the US. Approximately 50 Rascal sets are owned by iDTC, with typically "Teams" of one, two, or three campers using each set for one to two weeks through the summer.

RaC is based around a conceptually simple problem, pictured in Figure 6. The robot is required to "pick" the white sphere, which is held on the end of the chain by a small permanent magnet, and deliver the sphere to the cup.

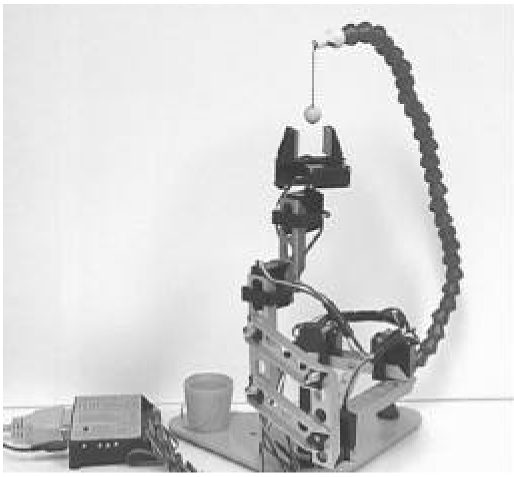

FIGURE. 6
A SPHERE SUSPENDED IN THE ROBOT WORK ENVELOPE

The current and planned stages of RaC are described next. We omit detailed description of the first three to four hours of RaC which acquaint the student with the physical and software components of the Rascal set.

Stage 1: Manual Control of an Articulated Machine

As part of the background material, it is pointed out to the Team that this category of course includes a great many of today's "nearly" robotic devices such as cranes, backhoes, and other construction machinery; and in broader sense, automobiles and tractor-trailers, especially when parking while backing up.

The Team then uses the Rascal software in Teach mode and with some patience is able to maneuver the robot to grasp the sphere, withdraw the sphere from its suspending magnet, and deliver the sphere to the cup. This is a somewhat familiar exercise since the Team has already used Teach mode in a similar way in earlier parts of RaC.

The Team is then directed to consider how this manual operation might be made more convenient, since the correspondence between the keyboard keys and the joints of the robot is not intuitive and makes for awkward operation.

To complete Stage 1, the Team submits a single page of notes and sketches to the Instructor about control improvements.

Stage 2: Sequencing of a Powered Machine

The Team uses Teach mode of the software to record a series of moves to "pick" the sphere and deliver it to the cup. Again, this is accomplished fairly quickly because of earlier practice on other robot constructions.

The Team is now directed to consider an advanced subject in preparation for Stage 3: Given a set of servo positions as displayed in the robot console, what is the position of the end of the gripper? The Team is required to discuss this complex question and submit a set of notes and sketches outlining possible approaches to its solution.

For those present readers unacquainted with the difficulty of this question, it is generally well beyond a bright high school or college student to derive unaided in any reasonable time. However, it is our expectation that a deep preliminary consideration of the problem will serve to prepare the minds of the students to more better understand the solution when later presented.

Stage 1, Revisited: Improved Manual Control

The Team is given the custom-constructed jointed controller, which looks exactly like their own arm, but which is wired internally only with encoders (potentiometers) and not with motor drivers. Thus, the controller directly mimics the geometry of the arm, and works with a software program which reads the potentiometers through the analog-to-digital inputs of the Rascal electronics, and links the motion of the controller to the robot. With this controller both the Stage 1 and Stage 2 activities become much simpler.

Stage 3: Kinematics Based Control

Teams are introduced to the mathematics of jointed robots, called "kinematics". The subject is a taxing one, and is not expected to be pursued by most Teams. However, with the aid of advanced graphics on the computer we are able to present the subject in a more comprehensible way than has typically been possible in textbooks. In addition, having prepared students by having them attempt the problem, even though without much success, we expect greater ability to grasp solution.

Regardless of the degree the students are able to comprehend the underlying mathematics, they are still able to use them in preprogrammed form to "pick" the sphere, this time given only its spatial coordinates, which are changed between "picks".

CONCLUSION

This paper presents our case studies on learning basics of mechanical design and spatial motion in the new conceptual framework of digital manipulatives. The courses were given at high school and college levels and focus on experiments and assignments. The students created mechanisms powered and controlled by servomotors and programmed their movements. This practice was based on the use of the robot construction kit Rascal. The projects related to various robotics applications such as drawing, chemistry laboratory experiments, biorobotics, creating toys, and others.

Assessment results indicated that activities with digital manipulatives promoted achieving learning objectives in all the courses presented in the paper. We found an important additional effect, namely, practice in designing and operating manipulatives throughout the course can improve the students' understanding of mechanics concepts, and their spatial imagery skills.

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