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AN EDUCATIONAL SOFTWARE FOR LOW COST MANIPULATORS

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Abstract

This study addresses the development of a novel educational tool for robotics education which can be used both in graduate and undergraduate introductory robotics courses. The tool both supports simulator and real controller mode. The tool has flexible characteristics that can be both used by commercial robotic research projects and also for educational issues. The flexibility of the proposed tool also lets researchers developing further modules within the software based on their research problems. The tool will be used in Ankara University for introductory robotic course during next semester. The aspect and software architecture are presented and the details of course curriculum, tool operation modes, learning objectives and software architecture are discussed in details. Finally, projects previously developed and implemented by the tool will be summarized in order to reveal the capacity of the tool.

***Keywords: -** Robotic Education, Manipulators, Software Design, Modular Architecture, Software Framework*

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1. INTRODUCTION

Simulation is a popular engineering tool allows researchers analyzing and testing real time systems. Computer simulation is employed to provide inexpensive training for the operation of complex and high cost equipments and it is also valuable in terms of saving time and efforts for research and teaching based issues. [1] Experimental designs and systems can be successfully verified without consuming machining efforts in the laboratories. It has been revealed that students can focus on improving their design in the projects and can easily obtain an instant feedback from computer within a simulator based education approach.

Robotic courses which accepted as a multidisciplinary approach in engineering are excellent tools for teaching general engineering concepts, especially in electrical, mechanical and computer engineering sciences. Robotic course at both introduction and advanced levels are offered by many universities all around the world. However, owing to the complexity of the robot geometry, lectures may need a physical robot to give the details of the subject. Besides, due to high maintenance costs of industrial robots, most universities cannot provide real physical robots for teaching and research activities, especially in developing countries. Computer graphic supported simulators can easily demonstrate robot arm movement with respect to the joint commands, allowing more students to attend the lectures and improve student comprehension of the material [2].

There are several works in this area, Wedeward [3], have focused on middle to high school students and have also developed comprehensive software programs utilizing mobile robotics as an educational tool for undergraduate [4] and graduate courses [5]. Most of these works are designed for simulator based education and do not provide any support to real time control of robot [6]. During in recent years, accessibility of small inexpensive mobile robots and low cost manipulators encourage attention of student to robotic as a multidisciplinary science in engineering education. CAD is an important industrial art which is mainly used for detailed engineering of 2D or 3D models. One of the early studies performed in this area can be seen in [7]. The study presents a robot system adapting a virtual reality approach enhanced by CAD design. One of the comprehensive studies in this issue addresses both the conceptual design and implementation of a solution for design and application of tripod-based parallel kinematic machines (PKMs) [8]. A more recent study introduces a novel intelligent robotic software system which can manipulate a low-cost five DOF robotic arm and provides the robot to play Tic-Tac-Toe ,a simple board game, with human competitors [9]. This system can be run in both simulation and real time modes.

One of the primary motivations for developing the simulator is to teach introductory robotic course in computer engineering department of Ankara University. The introductory courses focus on two key issues, namely technology-related robotics and theoretical fundamentals of robotics. The first course stresses industrial robot applications and the second includes the theoretical fundamentals of robotics [6]. The proposed tool matches in second category and supports introduction subjects. The earlier simulators in robotics not only did not support practical work but also need expensive robot arm. The developed education package tries to combine mentioned aims with the usage of low cost robotic arm which supports simulator and real time control modes. In this manner, a student can learn in simulation mode and practice in real time. Students are able to implement and execute robot control programs in off line mode without requiring any physical robot. The low cost robotic education tool (RET) simulates and controls commercial robot Lyxn6 [10].

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Actually, this robotic arm is designed for hobby and simple applications. Once a proper simulator is implemented and the computer based control of this arm is provided, it can be used for robotic education in graduate and undergraduate robotic courses successfully. The software has a flexible architecture and has been designed and implemented in C# language. Several software packages have been developed for educational issues. One of the most popular of these tools is RIOS [11] used with LYNX arm. RACS is well-known robotics software which is basically utilized to control AREXX robots [12]. Both of these softwares are used to control corresponding robots; however, they are only able to move robots' joints individually and calibrating servo motors. Besides, RIOS is able to support some simple complex movements for LYNX arms. Accordingly, they both have not been designed as robotics educational tool. Alternatively, Lego Mindstorms have been widely used in robotics education recently that is because they provide a flexible hardware design opportunity to the students. As well as, their software tool is user friendly which can even be used by students and researchers who are not experienced with bases of programming. However, it does not support modular programming and is not enough to handle several complex problems [13]. Comparing with existing applications and RET, the main advantage of the proposed tool is its ability to perform additional analyses and modular programming in robotic education.

This paper is organized as follows: The second section, addresses the goals, tasks and learning objectives of the education tool. The description of RET and architecture of simulator and capability of education tool with examples are addressed in the third section. The final section is about the empirical experiences through education and research focused on several areas of robotics.

2. EDUCATIONAL ISSUES: GOALS, TASKS and LEARNING OBJECTIVES

Simulator or educational tool in robotics is expected to cover a large spectrum of educational subjects in introductory robotic education for mechanical, electrical and computer engineering students. RET supports the main subjects in manipulator based robotic courses and are compatible with curriculum of theoretical classroom. Students are encouraged to learn control of simple motor, main part in robot arm motion control. The required background knowledge to employ the proposed tool properly includes linear algebra, motor control, feedback control, embedded control and pulse width modulation (PWM). This simulation tool essentially allows the kinematics analysis of the system; trajectory planning and speed control. Those who will utilize the developed educational simulator will be able to describe and understand following educational goals

- Workspace concept
- Degree of freedom(DOF)
- Forward and inverse kinematics analysis
- Modeling of manipulators in D-H frames
- Joint and Cartesian spaces
- Simple servo motor control
- PWM technique in motor control
- Trajectory planning in joint space (point to point)
- Trajectory planning in Cartesian space (Line or arc tracking)
- Control of grippers
- Embedded control of manipulators

As the simple servo motors which is used for controlling of joints are work with constant current, it is not possible to do additional dynamic experiment like torque control and force relations.

3. DESCRIPTION OF THE DEVELOPED TOOL

Simulators are well-established tools used for designing and analyzing of physical systems. Computer simulation allows users to achieve safe and low-cost training for the operation of complex and high-cost equipment. Simulators in education offer virtual laboratories to universities that can be easily adapted into a large variety of engineering and science courses. Developing a Simulator or educational tool in robotics is expected to cover a large spectrum of educational subjects in introductory robotic education. The earlier simulators in robotic did not support practical work or need expensive robot arm. With consideration of introductory subjects in robotic courses, RET is developed. As previously mentioned, it supports plugins which provides flexibility in high level structure that any corresponding module can be added to the main framework with minor modification. The tool supports a low cost and user friendly commercial robotic arm for practical experiments. Flexibility in hardware is related to support of robot arms having less DOF control than this commercial manipulator in real time control mode. One of the main intentions of this project is to employ the developed tool in undergraduate and graduate robotic courses. Furthermore, due to having a modular architecture and user-friendly graphical interface, it can also be adapted for self-learning and other associated research projects. Accordingly, both students and researchers can develop robotic projects under RET successfully. Additionally, handmade manipulators having less DOF and using simple RC servo motors can be supported by this package. For example, a simple handmade two joint planer robot having two servo motors can be controlled in both simulation and real time modes by RET which is a typical example for hardware based flexibility of the proposed tool. As previously mentioned, the proposed tool supports two application modes:

- Simulator
- Real time control mode

This simulator acts as virtual robot in two dimensions in which the tool renders virtual robot in two different angles top and left. It also displays signal values which are sent to serial servo controller. The simulation is controlled by a simple user interface and no programming skill is required to run the application. Several predefined tasks included to

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this simulator to encourage researchers to test and simulate some of fundamental characteristics of robotics. The designed educational tool is considered for senior undergraduate students and those who take part in graduate course of "introduction to robotics". PC is the main controller in real time control mode in which the results of user commands are sent to the robot arm using a SSC-32 servo controller [11]. The motion of joints can be controlled either in sequential or parallel manner. It is also possible to integrate different sensors to the overall architecture like cameras and range finder for the solution of more complex problems [9].

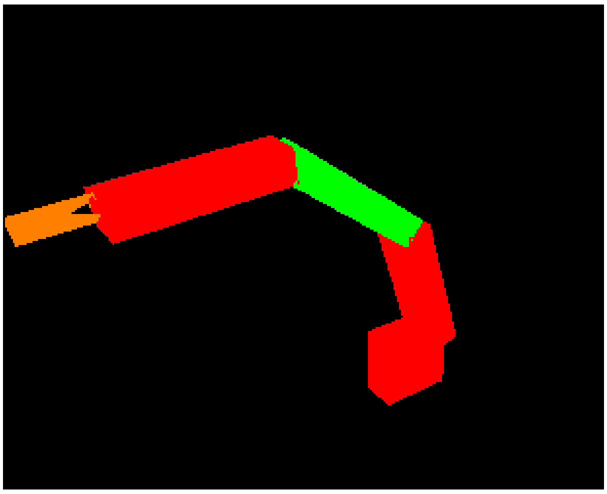
3.1 Lynx-6 Robot Arm

Lynx6 robot arm has 5 DOF with a grip movement, as illustrated in Fig. 1. This arm resembles human arm and can deliver fast, precise and repeatable movement. Robot arm's joints are namely, shoulder rotation, shoulder back, and forth, elbow, wrist up and down, wrist rotation, and gripper respectively. This robotic arm is low-priced, flexible and primarilyconsidered for educational issues. Servo motors, using pulse controlled local feedback, offers an accuracy of "0.9" degrees per axis, and can be used in all of joint and in gripper of the robot. It has been experienced that these servo motors decreases the complexity of feedback control mechanism that allows more precise movement of corresponding joins [9].

3.2 Software Organization

As outlined before, educational tool supports two main operation modes, namely, simulation and real time (physical) control modes. User commands are obtained in both modes. For real time applications, PC is the main controller and sends outputs of user commands via serial servo controller to servo motors.

(a)



(b)

Fig 1: Lynx6 Robotic Arm [10], a) Physical Arm, and (b) 3D Model of the arm.

The Software can control associated manipulators with trivial parameter modification. The simulator part of the software is also simulating motional characteristics of manipulator. The general architecture of the proposed software is illustrated in Figure 2. The second level of the architecture demonstrates the plugins layer, allowing students and researchers to develop their own GUI components and also implement customized algorithms for solving different problems.

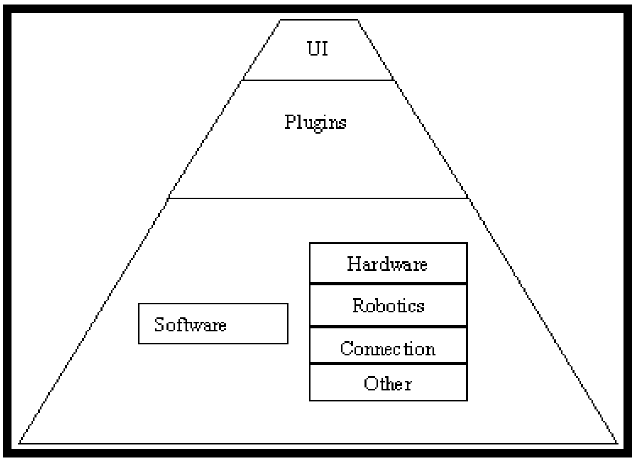


Fig 2: The general architect of software [9].

The running principle of the proposed plugin architecture is so simple that the system first searches for all possible installed plugins and then run all detected plugins. Each module of the tool is implemented inside this plugin based structure. Accordingly, arm simulator, forward kinematics (FK), inverse kinematics (IK), serial connection and matrix library modules are implemented as plugins and can be modified without compiling the main software. The modification occurs only in the required module that recompilation of corresponding plugin is enough to update the tool. Each plugin can access neighbouring modules'

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data. For instance, FK module is allowed to access the data of FK module and vice versa. Besides, data of both plugins can be accessed from arm simulator plugin. Also each plugin employs serial connection plugin in order to connect with physical robot. As a future work, serial connection can be replaced with Wireless Bluetooth or other type of connections. Essentially, this flexible structure of the plugin based structure makes the proposed tool is a good alternative for whom working with robotic and related fields. As a result, graduate or undergraduate level students can implement their personal algorithms and applications without considering the architecture of the whole system. The software architect will consist of different properties and engines as defined:

- **Graphical User Interface (GUI)**
  The GUI allows the interaction between the user and the simulator. It is expected from the GUI to represent the state of the simulation to the user and to lead the user for step by step learning.
- **The Simulation Engine**
  The Engine is responsible for modelling the physical robot, constructing data structures to characterize the robot, and operating the robot's joint angles, as stated by simulation commands within defined kinematics or dynamic solutions.
- **Simulation File Parsers**
  This module is considered as the intermediate layer and responsible for parsing files for simulation commands, definition of physical model of the robot and solved kinematics equations. These files control the interior model of the robot, which is both employed to simulate and physically control the robot.
- **Mathematical Engine**
  This engine is responsible for solution of kinematics equation and calculation related joint or Cartesian values. As well as, it is responsible for complex matrix based calculations.
- **Real Time Engine**
  This section is related with control of robot arm in real mode control. Calculation of pulse widths due to joint values and send to output port is achieved by this engine.

As previously introduced, the tool suggests two operation modes in startup (simulation or real mode control). In the simulation mode there are options for leaning that the user can learn fundamentals of robot manipulators step by step. For example, students can learn the concept of DOF by enabling the joints of robot in different variations and follow the result of motion in simulation or real time motion.

For improving self-learning task of the tool, there is determined a reach help section which includes fundamental subject in robotic in general and especially about supported robot. Some of help subjects are shown as follows;

- Definition fundamental subjects in robotic (DOF, Workspace and etc)
- Definition of simulated robot
- Operating and control of RC motors.
- Learning of forward and inverse kinematics with example calculation for Lynx6 Arm and related equations through D-H method.
- Trajectory planning (joint or Cartesian) and related calculation
- Operation of DC motor and PWM control and working of RC servo motors

Several screens of simulator operations are shown in figures 3 - 6. Figure 3 illustrates start window which is the initial screen of the tool whereas figure 4 is about DOF learning screen. Screen of motor control is shown in figure 5 and figure 6 indicates trajectory planning. For example, in a liner tracking (Figure. 6) the user selects start, end position and number of segments in Cartesian space and run the associated mode.

Fig 3: The main window of RET (mode selection).

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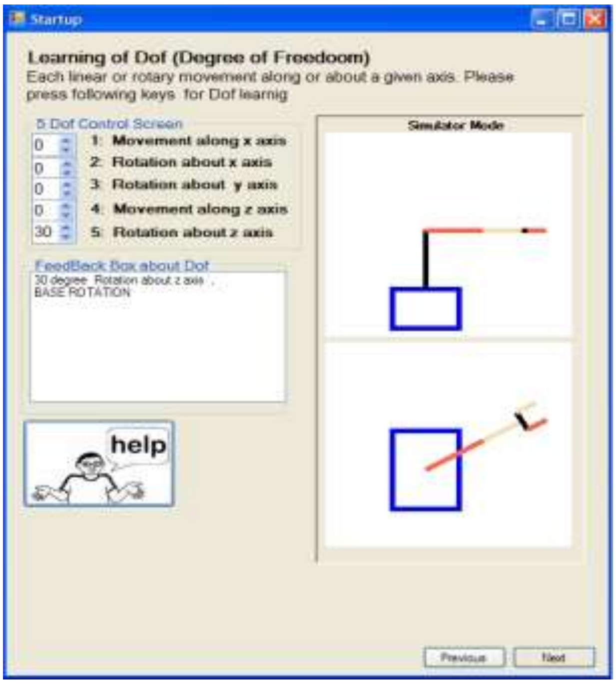

Fig 4: Screen of learning DOF.

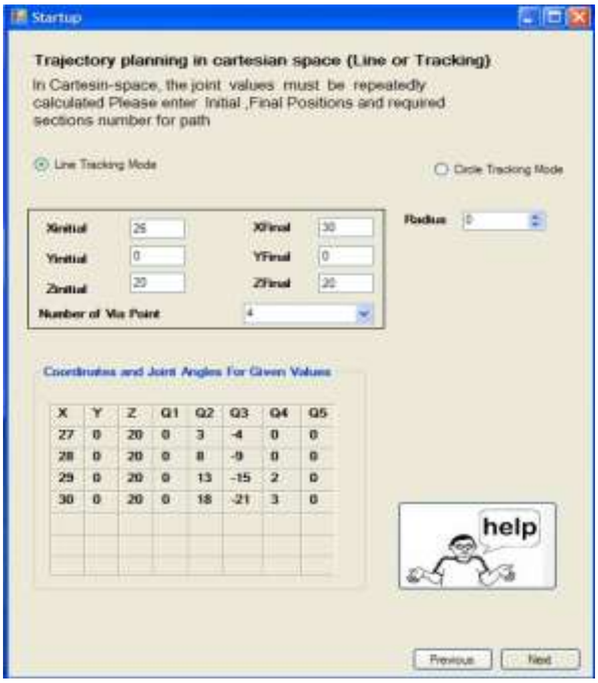

Fig 6: Screen of trajectory planning (Cartesian).

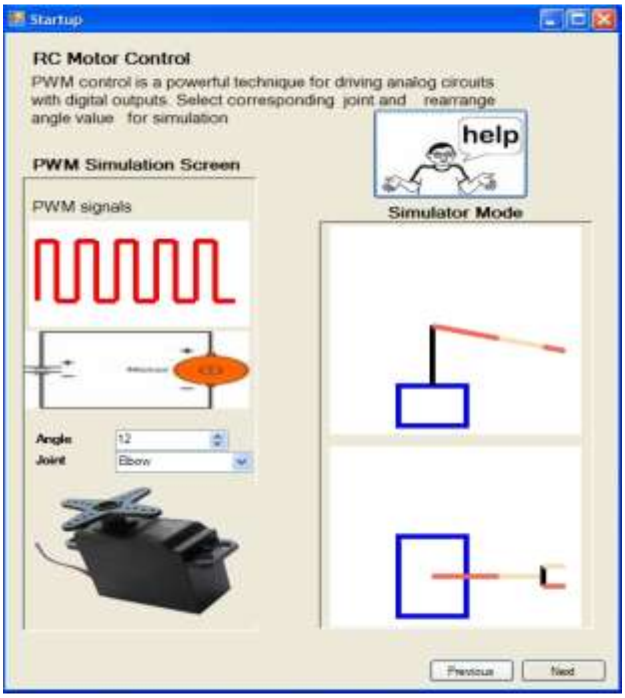

Fig 5: Screen of learning of RC motor.

3.3 RET in Real Time Control

All of learning options discussed in simulation mode can also be performed in real time control mode. An example of working environment is shown in figure 7 in which the selected parameters about motors of joints are transferred to motors via serial servo controller (SSC-32). As outlined before RC motors are fully pulse controlled actuators. The value of pulse widths which sent to servo controller can be seen in every mode. Position control of motors is related to pulse widths and speed control of motors is possible with inserting addition delay loops between control pulses.

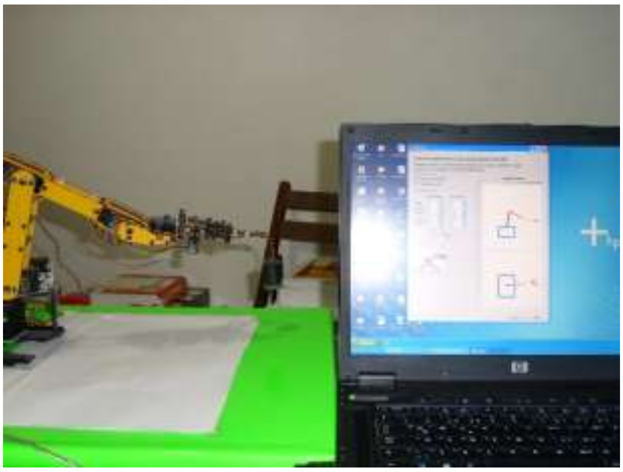

Fig 7: Real time mode.

Real time engine is responsible for converting calculated joint values to control pulses and sending this pulse to servo controller in real time. SSC-32 servo control card is a preferred alternative for Lynx6 robot arms and counselled by the producer company. Once a command is applied by

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the software, a sequence of 3 successive unsigned bytes is directed to the servo controller. These bytes are sync byte, the joint identifier and the desired position of the motor respectively. Each servo has a discrete value with absolute positioning, hence each angle value must first be converted into a discrete value, illustrating the ultimate servo position [10]. The total number of controlled motors can be easily manipulated by the proposed software which can either enable or disable any joins depending on the problem.

4. CLASSROOM ASSESMENT

The tool was introduced during the 2016 autumn term with 30 students. The course continued 14 weeks. Each week, there was two hours theoretical sessions and one hour recitation session that takes place in the laboratory. Theoretical study includes fundamental subjects of robotics namely, introduction to robotic, linear algebra in robotic, fundamental concepts in robotic (joint, link, workspace, DOF and etc.). More advanced topics including dynamic analysis and forces, trajectory planning and mobile robots were also introduced during the course. The first laboratory work took place in PC based laboratory and include mechanical presentation of Lyx6 robot arm, presentation of tool and simulation based learning workspace and DOF. In simulation based training, the first lecture described the workspace concept whereas the second evaluated the limits of the simulated arm with respect to the degrees of freedom of joints (DOF). Students were encouraged to perform a series of experiment in simulation environment. At the end of each simulation based work, some of the selected experiments were conducted by actual robot. Students are also encouraged to design and implement term projects with RET. A survey has been applied to the students to analyze the tool's performance on education. Final result reveals that all students registered into the course accept that the tool increases their learning skill in robotics, however approximately one-third of all students complain about the shortage of physical robots. Accordingly, this survey and the course taught give us beneficial feedback in terms of integrating the tool into the course took place on 2017 spring.

4.1 The Evaluation and Analysis of RET

As mention before, the student attended introduction to robotic course next semester. The robotic introductory course is an elective course for senior undergraduate students. In parallel with course curriculum, the simulator was available for student to work in home and conduct personal projects. The tool was tested with a group of undergraduate and graduate students working on robotics projects last semester in order to have some feedback for the next semester course. The Students' response to the performance and efficiency of the tool was obtained through evaluation sheets. The feedback obtained about the tool was quite positive which proves the effective learning and student pleasure from simulation based learning. The advantages of using this tool in robotic learning can be explained as follow:

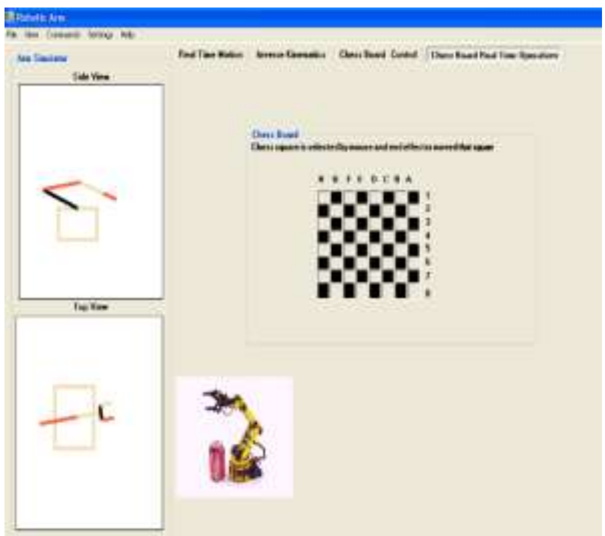
- Increase student interest in robotics and corresponding fields.
- Observing the results of theoretical learning in terms of robot action in both simulations and real environments.
- Possibility of having low cost robots by student for assignments or self-learning increases effective learning.
- Flexible structure of the tool supports new modules which increase the possibility of developing new ideas.

An example can be seen in Figure 8 in which the physical robot and the simulator works at the same time. This also proves that the robot and the simulator can be worked together.

Table 1: The Result of the experiments [9]

Game number(15), X(AI) ,O(Human)			
X won	***O won***	***Draw***	***Percentage of winning***
9	***0***	***6***	***%60***
13	***0***	***2***	***%86***
7	***0***	***8***	***%47***
12	***0***	***3***	***%80***
10	***0***	***5***	***%66***
8	***0***	***7***	***%53***

For instance, when physical robot arm moves towards a target, the simulator also simulates the robot's action. The simulator can be employed to control the physical arm manually which in essence was implemented as considering the physical limitations of the robot arm used. Consequently, simulation results can be adapted to physical robot in order to examine the given input. Especially in trajectory planning and kinematics analysis of the robot arm, simulation results can be used as preliminary evaluation of the overall system. A further experiment was conducted in order to evaluate the deviation between the simulator system developed and the real system based on a physical robot.



a) Simulator

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b) Real experiment on chessboard

Fig 8: Test environment, a) simulator, b) real experiment.

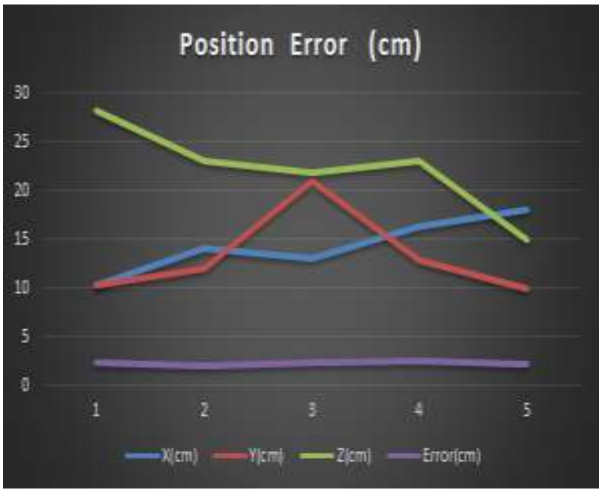

Fig 9: Position error between the simulator and physical robot

The test environment can be seen in Figure 9 and the corresponding results are illustrated in Figure 10. The experiment in essence aims to assess the deviation between the simulator and the robot's end effector position after having the same input position on the board. Results reveal that the deviation is only a few cm (less than 2.5 cm) which proves that the simulator results are quite similar with the physical system established.

4.2 Robotic Projects using RET

We acknowledged that some parts of this study were published at [9]. Besides, several projects have been developed using RET, and some of these have been published recently. One of these projects is a user friendly software package which was proposed to simulate the motional characteristics of a robot arm having variable number of Degrees-of-Freedom (DOF) parameters [14, 15]. An example of the program screen with the corresponding application is illustrated in Figure 10. Another application developed based on RET is a user friendly application for dynamic analysis of a Lynx-6 robot arm's actuators. Dynamic modeling of DC motors is first presented. Afterwards, their collaborative motion based on a robotic arm is analyzed and simulated using a 2-D simulator [16]. Figure 11 illustrates the entrance screen of the proposed application, derived from the RET, in which, the tool analyses, actuators, DC servo motors and is able to estimate motional characteristics of manipulator by solving both inverse and forward kinematics equations.

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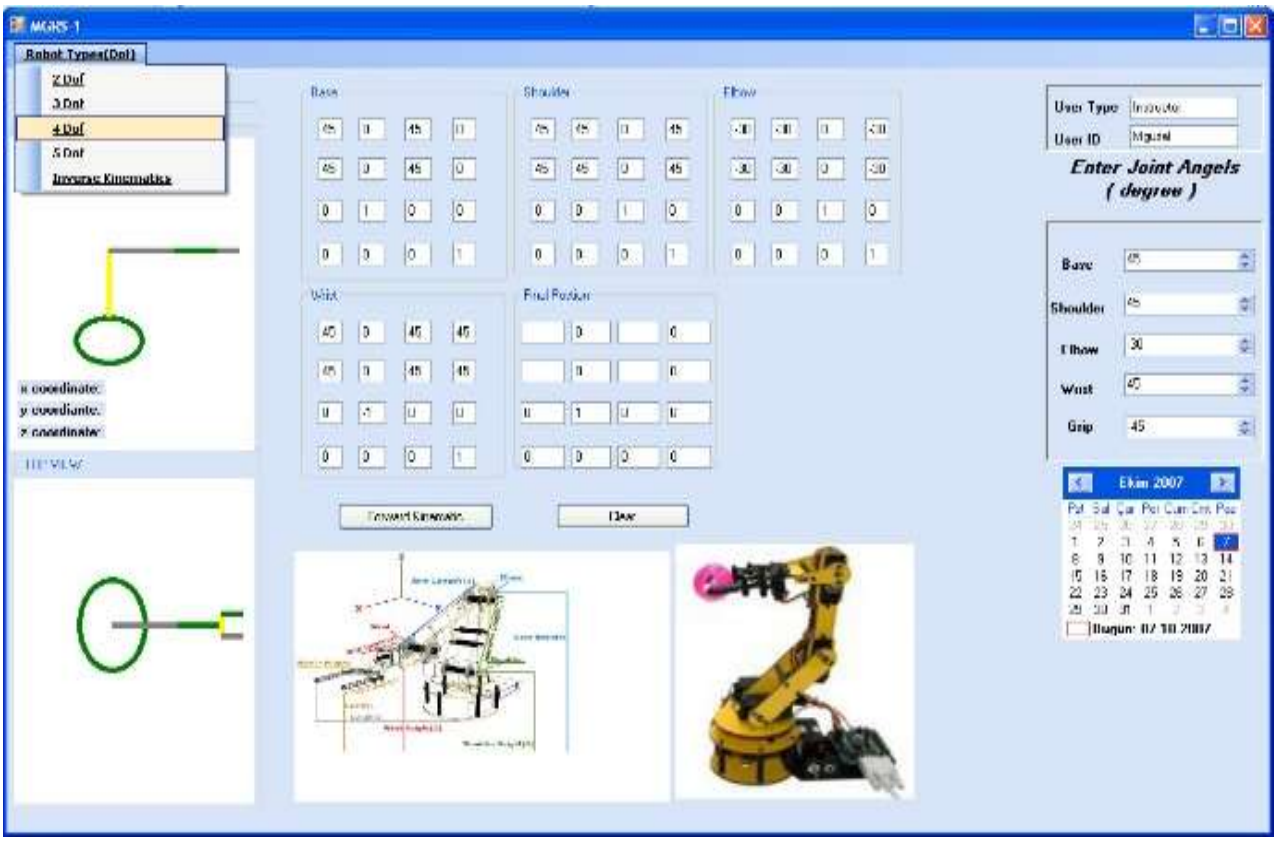

Fig 10: Forward kinematic screen (4 DOF) [14,15].

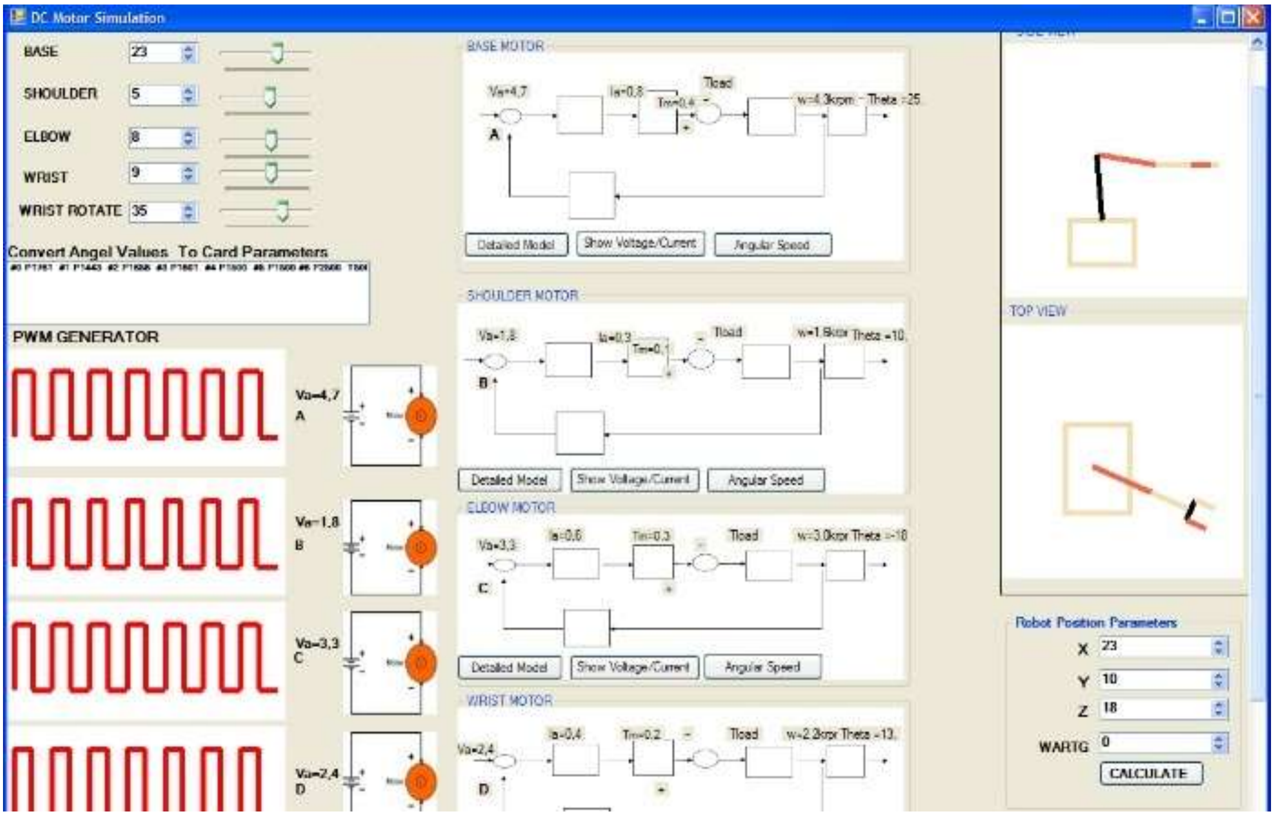

Fig 11: Main Screen of the application [16].

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The final application developed using RET allows a physical robot to be able to play tic-tac-toe, a simple strategy game, against any human opponent. In order achieve this, the robot arm is equipped with a simple low-cost monocular camera which is primarily employed to detect and analyze the game board, providing inputs to the developed AI engine. The AI engine essentially utilizes min-max tree algorithm as the major control and decision algorithm of the proposed system to estimate the next best possible movement for the machine (robot arm). Consequently, the proposed robot arm system works in a fully autonomous manner without requiring any human contribution during the game session [9]. An example view of the test environment is illustrated in Figure 12. Table 1 demonstrates the test results of the proposed intelligent framework for tic-tac-toe game in which five different humans coming from different ages having different professional skills are obtained for the experiments. The results verify the performance of the proposed AI mechanism. They system it is unbeatable that the best result can be obtained by a human user against the system is a draw. The following link illustrates the application [9]:

http://www.youtube.com/watch?v=HFuBMOLuAn0

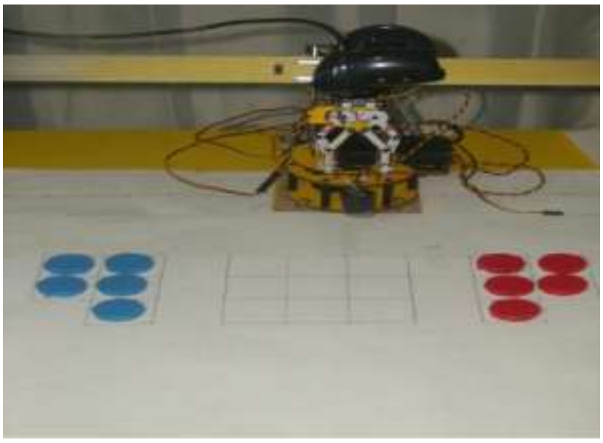

Fig 12: Application environment of the RET [9].

5. CONCLUSION

In this study, an educational tool for manipulator based robotic learning has been introduced. The tool supports low cost learning and teachingmethodologiesin robotics and related courses. The tool mainly helps students to improve their learning skills on robotic fields with respect to the simulation and real time control modes. Educational experience indicated that simulation based learning is better than theoretically based learning. On the other hand, most of the learning procedure is performed by the simulation mode, which is essentially supported by practical experiments, allowing to obtain best results. Preliminary experiments conducted during the evaluation of the proposed tool also revealed this fact that learning through simulation should be followed by real experiments to increase efficiency and provide consistency. Another significant advantage of the tool is its adaptation to employ a low cost manipulator which in essence helps researchers and students to conduct real experiments easily. Student feedback shows that simulation based learning especially in robotic field is quite effective and beneficial. The more effective learning can be observed once simulation and real time control occur simultaneously. The rich help menu of the tool provides self-training in robotic education. The software architecture of the developed tool comprises a modular structure that supports plugins in order to ease researchers to design and implement various applications in the field of robotics.

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