

# Motivational Laboratory Projects in Undergraduate Robotics Education

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**Abstract:** Laboratory student projects are the most important part in the learning process at engineering studies. This is particularly important in applied fields such as robotics. The laboratory experience should give the students knowledge of the equipment, working habits and introduce a close relationship between theory and practice. The purpose of this paper is to present motivational laboratory projects for the robotics course based on the use of industrial robots. The presented projects are directly related to the lectures on homogenous transformations, robot geometrical model and robot position and force control. A survey, carried out among students, shows that the laboratory student projects are motivational and theory related.

**Keywords:** Robotics, Laboratory practice, Homogenous transformation, Robot geometrical model, Robot control

## 1 Introduction

The Faculty of Electrical Engineering, University of Ljubljana educates engineers in the field of electrical engineering. The education process is divided into the programs of telecommunications, control engineering, robotics, biomedical engineering, mechatronics, renewable energy sources and multimedia communications.

The undergraduate study at the faculty is split in two divisions, the *University Programme and Applied Electrical Engineering*, both of them on the 1st degree (3 years) of the Bologna study. The *University Programme* gives besides practical knowledge also knowledge that future electrical engineers need for autonomous development and research. The *Applied Electrical Engineering* programme gives more practical knowledge which is mainly used in industry.

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The article describes three out of six laboratory projects of the Robotics subject of *Applied Electrical Engineering* study programme. We present also the results of the student survey in order to find out whether the exercises are motivational, theory related and if evaluation approach is appropriate.

## 2 Robotics subject

The Robotics subject is part of the 2nd study year in the 4th semester of the *Control Engineering* program. It consists of lectures and laboratory practice, both for 2 hours per week. The lectures are attended by all the students at the same time and place. The students are presented with homogenous transformation matrices, geometric description of the robot mechanism, kinematics and dynamics of a two-segment robot manipulator and robot positional and force control. All presented subjects are available to the students in Slovene [1] and English [2] as a textbook, written specially for students of the Robotics study course.

In the literature many different methods can be found for the

execution of laboratory practical work. These can be split in *traditional* and *non-traditional* methods. Some authors [3] present the method based on Vee mapping and called *Laboratory Practice Based on Questions* (LPBQ) very motivating. These questions are answered by an appropriate laboratory project. Another approach called *problem-based learning* can be categorized as a *non-traditional* learning approach [4]. It is highly motivating for the students and it is based on solving real problems in the educational field. Most frequently the laboratory practical work is based on the method called *predefined laboratory projects for the students* and belongs to the *traditional* [3] method group. Our teaching method combines the *problem-based learning* and *predefined laboratory projects* methods. For this approach the students need to use the lecture textbook and also a special textbook [5] as a guide for the particular laboratory project.

When the laboratory student projects were being designed, the student motivation was of primary importance. Nowadays much experience in the field of robot control and ro-



**Figure 1.** Project robot system

bot cell manufacturing can be acquired by computer simulation and animation [6]. This approach enables execution of laboratory projects in smaller places and also the running costs are lower because there is no need to purchase hardware [7], [8]. However, this approach has its drawbacks. The quality of simulation is proportional to the exactness of the mathematical model that is running in the background [9] and in the simulation environment is very hard to include proper information from different sensors integrated in a robot work cell.

The approach where real industrial robots are used is appreciated also in the literature [10] because the students gain more experience while working with real robots and solving real problems. This kind of approach motivates [11] the students to work and solve laboratory projects with great enthusiasm. In our laboratory we have several industrial robots of different types and almost all laboratory practical work is performed on real robots. Besides, during the laboratory practice the students get familiar with the use of a robot vision, geometry, different sensors, control approaches, pneumatic equipment and use

of different robotics programming languages.

The students have to pass 6 laboratory projects, each taking 4 hours. Four projects (Object manipulation with SCARA robot and robot vision, Synchronous work of two robots, Robot working with the object on the conveyor belt, Position and force control of anthropomorphic robot) are performed with real industrial robots and are related to industrial applications. The remaining two

exercises (Geometric model of the anthropomorphic robot mechanism, The use of homogenous transformations in Matlab) are theoretical and executed in Matlab. A group of students for each laboratory project consists up to 3 people.

### ■ 3 Object manipulation with scara robot and robot vision

#### **Project goal**

In this project the students train the usage of homogenous transformations and relations between coordinate frames. All the procedures are described in the textbook and the students' task is to understand the details to derive the project.

#### **Hardware**

The most important part of the project is the robot Epson E2S651 (Figure 1) with 4 DOF (Degrees Of Freedom). It is controlled by a PC-based RC420 controller. At the robot endeffector a pneumatic gripper with special fingers for gripping round bottle caps is attached. Opening and closing of the gripper is controlled by an electro-pneumatic valve that is electrically connected to the controller IO interface.

Above the work table a video camera is attached with a CCD sensor with 640x480 pixels, equipped with 8 mm optics and connected to the robot computer by Firewire interface. For laboratory project purpose the students use plastic bottle caps. These are 14 mm high and 40 mm in diameter. For screwing of these caps a matrix of 12 plastic bottle influx is fixed in robot working area.

#### **Software**

The robot Epson E2S651 is programmed through the Windows based Epson RC+ environment. The acquisition, distortion elimination and processing of the image and all calculations of homogenous transformations run in Matlab development environment. The communication between Epson RC+ and Matlab environment is achieved by TCP/IP protocol.

#### **Student project**

The project is split in two parts. In the first part the students are introduced with the robot system, basic robot movements and IO commands. In the second part the students' task is to write only a part of the whole Matlab program that recalculates the bottle caps position in the reference robot frame. This recalculation involves the calculation of the camera frame in the robot reference frame, which can be determined only by calibration procedure described further in the article. When all calculations are performed a few caps are placed into the camera field of view that is part of the robot work space. In Matlab, with the use of pre-written functions, the camera image is captured and the position of the caps in camera field of view is returned.

#### **Theory**

The aim of this laboratory project is the students' understanding of relations between the robot, camera and object frames. This enables the students to understand how to define the homogenous matrix of video camera frame alignment within the robot reference frame. This procedure is in detail described in the laboratory projects textbook.

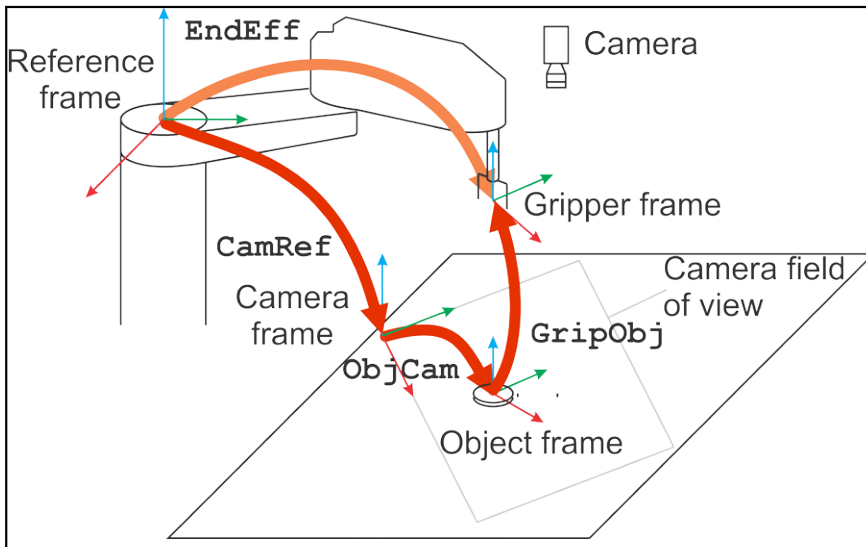


Figure 2. The transformations before gripping the object

In the laboratory projects textbook all the frames are shown as in Figure 2. The two basic frames are: reference and gripper frame. Beside these two, also the camera and object frames are present. The one of the camera is positioned in a corner of the camera field of view.

The gripper pose (**EndEff**) in robot reference frame can be defined, not only by reading of the pose directly from Epson RC+ environment, but also from the camera frame expressed in robot reference frame (**CamRef**), the object frame in camera frame (**ObjCam**) and the gripper frame in the object frame (**GripObj**) (1):

$$\mathbf{EndEff} = \mathbf{CamRef} \cdot \mathbf{ObjCam} \cdot \mathbf{GripObj} \quad (1)$$

This relation is simplified when the gripper grasps the object and both frames are aligned. In this case the homogenous transformation **GripObj** becomes identity matrix **I**. Further, it can be shown that when the pose of the gripper in robot reference frame is known when the object is grasped and also the pose of the object in camera frame is known, then the pose of the camera frame in the robot frame can be calculated (2):

$$\mathbf{CamRef} = \mathbf{EndEff} \cdot \mathbf{ObjCam}^{-1} \quad (2)$$

In the textbook the students are

presented with a detailed procedure of how the camera frame is related to the robot reference frame. The procedure is as follows. In the camera field of view a sheet of paper is placed. On this paper three large black dots are printed. These three dots represent a frame of the object (Fig. 1). The dots are 180 mm apart.

In Matlab environment the students need to run a function for capturing the camera image and function for selection of all three dots. The user needs to follow the order of selecting the dots; first dot T1(x,y) represents the origin of the frame, then T2(x,y) is a point on x axis and T3(x,y) a point on y axis of the object frame. The function returns the coordinates of the dots in pixels as a vector  $T = [T1, T2, T3]$ . This vector must be converted to millimeters ( $P = [P1, P2, P3]$ ) as shown in equation (3):

$$P = T \cdot \frac{180}{\sqrt{(T2_x - T1_x)^2 + (T2_y - T1_y)^2}} \quad (3)$$

Point P1 is a position of object frame origin in camera frame. To describe the object pose also the orientation is needed. It is calculated from the angle of rotation  $j$  between both x axes of the object and the camera frames (4):

$$\varphi = \arctan \frac{P2_y - P1_y}{P2_x - P1_x} \quad (4)$$

The calculated data give all the information for determination of homogenous transformation **ObjCam** that describes the pose of the object in camera frame (5).

$$\mathbf{ObjCam} = \begin{bmatrix} \cos \varphi & -\sin \varphi & 0 & P1_x \\ \sin \varphi & \cos \varphi & 0 & P1_y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

With the described procedure the **ObjCam** matrix in equation (2) is determined, but for calculation of **CamRef** matrix also the **EndEff** matrix is needed. This procedure is also described in the laboratory textbook. The most important detail of the procedure is that the white paper must not be displaced in the camera field of view during these matrix calculations.

The procedure of defining the pose of the object frame in the reference frame is as follows. In the gripper center a special adapter with a nib is fixed. To define the pose of the object frame, first the position of its origin in robot reference frame is needed. This information is acquired when the tip of a nib is in contact with the center of the origin dot (T1). The value of this coordinate in millimeters is displayed in Epson RC+ environment and is manually entered into the Matlab environment as the first component Q1(x,y) of the **Q** vector. To define the orientational part of the pose, the same procedure is used, with the only difference of contacting the dot on the x axis of object frame as the point Q2(x,y).

The procedure how to define the orientation of the object in reference frame is the same as for **ObjCam** matrix (6):

$$\vartheta = \arctan \frac{Q2_y - Q1_y}{Q2_x - Q1_x} \quad (6)$$

We have now all data needed to calculate homogenous transformation matrix that defines the pose of the object in robot reference system where the letter Z stands for the predefined value of vertical move-

ment of the end-effector when the cap is grasped (7):

$$\mathbf{EndEff} = \begin{bmatrix} \cos \vartheta & -\sin \vartheta & 0 & Q1_x \\ \sin \vartheta & \cos \vartheta & 0 & Q1_y \\ 0 & 0 & 1 & Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (7)$$

When both homogenous matrices **EndEff** and **ObjCam** are defined, the third matrix **CamRef** can be calculated (2) and further used to calculate (8) the position of the bottle caps in the reference robot frame:

$$\mathbf{EndEff} = \mathbf{CamRef} \cdot \mathbf{ObjCam} \cdot \mathbf{I} \quad (8)$$

In this project the orientation is not important, since the robot grasps round objects. However, because this is an educational example, the students are presented with the general procedure and must treat the object orientation as well.

## ■ 4 Geometric model of anthropo-morphic robot mechanism

### Project goal

The goal of this project is to educate students how to mathematically describe the pose of the Epson PS3 robot endeffector in robot reference coordinate frame. This exercise represents training for the written examination, only the robot structure is different.

Kinematic pair is considered as the basic element of the robot manipulator. It consists of two robot segments connected with a translational or rotational joint. To describe the kinematic pair mathematically, the Denavit-Hartenberg [12] method is mainly used. In this project the model is obtained with different method that uses vectors [13] to mathematically describe the kinematic pair. This approach for determination of the kinematic pair parameters is much easier [14] and more suitable for students' understanding.

### Software

In this project the students use Matlab development environment to

fill a template with kinematic pair parameters that are previously written on a sheet of paper. These parameters are input parameters of pre-written special functions that generate proper homogenous matrices.

For the end result checking, a special Graphical User Interface (GUI) was developed, where the students fill in the selected values of joint variables for the robot. By clicking a button in GUI the filled template is run. As a result, the pose of the end-effector in the reference frame in the form of the homogenous matrix and in Euler angles is displayed. The results can be checked by the laboratory projects textbook where the correct results for selected joint values are written.

### Theory

The method to geometrically describe the robot manipulator with the use of vector parameters is included in the lectures on robotics [1], [2]. Its basic idea is to use homogenous matrices to describe the pose of the end-effector in reference frame. The method prescribes how the particular joint frames are placed on the manipulator to calculate the end-effector pose from the joint variables. The method prescribes the following steps:

1. The robot mechanism must be placed into the home position, where the joint variables are equal to 0 ( $J_i = 0$  and  $d_i = 0$ ,  $i = 1, 2, \dots, n$ ). This rule must set the joint axes parallel to one of the reference frame axes  $x_\sigma y_\sigma z_\sigma$ .
2. The centers of the joints  $i = 1, 2, \dots, n$  are selected. The center of joint  $i$  can be anywhere along the corresponding joint axis. A local coordinate frame  $x_i y_i z_i$  is placed into the joint center in such a way that its axes are parallel to the axes of the reference frame  $x_\sigma y_\sigma z_\sigma$ . The local coordinate frame  $x_i y_i z_i$  is displaced together with the segment  $i$ .
3. The unit joint vector  $e_i$  is allocated to each joint axis  $i = 1, 2, \dots,$

$n$ . It is directed along one of the axes of the coordinate frame  $x_i y_i z_i$ . In the direction of this vector the translational variable  $d_i$  is measured, while the rotational variable  $J_i$  is assessed about the joint vector  $e_i$ .

4. The segment vectors  $b_{i-1}$  are drawn between the origins of the  $x_i y_i z_i$  frames,  $i = 1, 2, \dots, n$ . The segment vector  $b_n$  connects the origin of the  $x_n y_n z_n$  frame with the robot end-point.

Following these steps, a table is built with appropriate vector parameters and homogenous matrices are written. After the multiplication of matrices, the end result is another homogenous matrix that describes the robot end-effector pose in reference frame.

### Student project

Students build the geometrical model by using the vector parameters for robot Epson PS3 with 6 DOF. At the start a sheet of paper (Figure 3) with the robot home configuration is given to the students. On this sheet of paper vectors  $e_i$  are not drawn. The depicted robot correspond to step 1 of the method, where all joint variables are 0 degrees. This figure also shows: the reference coordinate frame pose, the small black dots that define the positions of the centers of the joints, the distances in millimeters between the joints and joint positive rotations of the selected robot.

Next the students draw on the sheet of paper the unit directional vectors  $e_i$  that define positive rotations of the individual robot joint. At this point the students need to be careful, because the direction of the vector  $e_i$  for joint 4 and 6 is opposite to the  $y$  axis of the local or reference frame. This is because the selected robot has the positive rotation defined as clockwise, which is considered negative in robotics textbooks. This situation is shown by Figure 3 where vectors  $e_i$  are included.

In the last phase of the method the segment vectors  $b_{i-1}$  need to



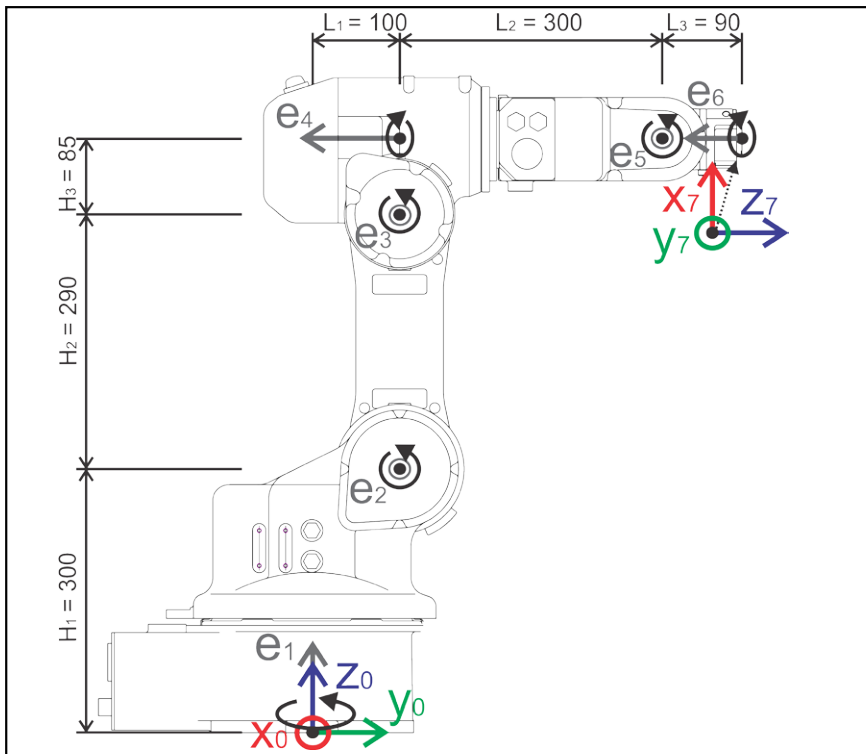


Figure 3. Epsilon PS3 sketch including dimensions

be drawn. These vectors show the information of the direction and distance between the robot joints. Regarding to the drawings the students construct a table (Table 1) including vector parameters:

to include another transformation  ${}^6H_7$ , to align the last frame with the one on the real robot. The students receive the resulting end-effector pose in reference frame as a homogenous matrix  $T$ , calculated by pro

Table 1. Vector parameters

i	1	2	3	4	5	6
$\vartheta_i$	$\vartheta_1$	$\vartheta_2$	$\vartheta_3$	$\vartheta_4$	$\vartheta_5$	$\vartheta_6$
$d_i$	/	/	/	/	/	/
$e_i$	0 0 1	1 0 0	1 0 0	0 -1 0	1 0 0	0 -1 0
$b_{i-1}$	0 0 0	0 $L_1$ $H_1$	0 0 $H_2$	0 0 $H_3$	$L_2$ 0 0	$L_3$ 0 0

When the table is written the students use special functions for generating homogenous matrices. With these functions the template file for the robot Epsilon PS3 is filled. Homogenous matrices define the pose of individual local coordinate frame in the previous frame:  ${}^0H_1, {}^1H_2, {}^2H_3, {}^3H_4, {}^4H_5$  and  ${}^5H_6$ .

The selected robot has the last coordinate frame oriented as shown in Figure 3, marked with number 7. To compare the calculated pose with the real robot pose it is necessary

per matrix postmultiplication order (9) where selected values of joint variables values  $J_i$  in  $d_i$  are included:

$$T = {}^0H_1 \cdot {}^1H_2 \cdot {}^2H_3 \cdot {}^3H_4 \cdot {}^4H_5 \cdot {}^5H_6 \cdot {}^6H_7 \quad (9)$$

### 5 Position and force control of anthropomorphic robot

#### Project goal

The goal of this project is to teach students how the simplest proportional (P) controller for position and force control of the robot end-point

in reference frame is behaving. In robotics this kind of control is called *control of the robot in external coordinates*. The project demonstrates to the students that the robot end-point can be controlled by its position in robot space or by contact force that acts between the robot end-point and environment [15]. During the project also the influence of the proportional gain on system stability is studied.

#### Hardware

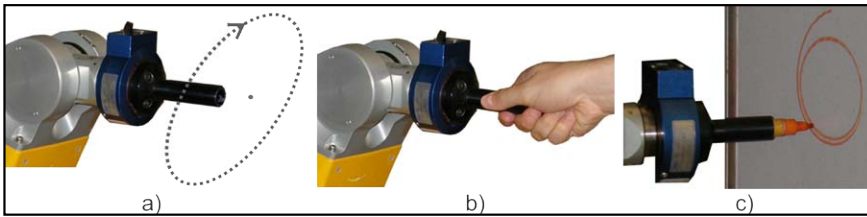
In the presented student project the robot Staubli RX90 is used. It has 6 DOF, all joints are rotational. The original robot is a position controlled system, however in our laboratory it was redesigned into a force controlled (haptic) device [16]. For the force control a force and torque sensor JR3 85M35A-I40 is attached to the robot end-point. On the force/torque sensor a handle for human interaction is attached which is also used for attaching a marker pen.

#### Software

For the control of the robot in addition to the position controller, a special controller was developed. The haptic controller runs in real-time MathWorks xPC Target environment [17]. Programming of the robot movements takes place in Matlab Simulink environment. A special GUI enables xPC Target start and stop of the controller (position, force and position&force). For the simplest interaction for the students an *Embedded Matlab Function* object as a program template is included. In this template the students write their own highlevel controller. This object has several input parameters:

- $p_s$  ... end-point start position  $(x_s, y_s, z_s)$ ,
- $p$  ... end-point current position  $(x, y, z)$ ,
- $f$  ... current force at the end-point  $(f_x, f_y, f_z)$ ,
- $t$  ... current time,
- $K_p$  ... position controller proportional gain,
- $K_{pf}$  ... force controller proportional gain.

The output of the *Embedded Matlab Function* object is a velocity vector  $v$  of the end-point  $(v_x, v_y, v_z)$ . This



**Figure 4.** Robot is position (a), force (b) and position/force (c) controlled

vector is a reference value for much more complex low-level controller that controls the robot in the joint space.

### Student project

The project is divided in three parts. In the first part the students make the robot Stäubli RX90 end-point to move (Figure 4a) along a circle in vertical  $yz$  plane of the reference frame  $(x_0, y_0, z_0)$ . This is the position control of the robot.

In the second part of the project students are introduced with the robot force control by the use of the proportional force controller. This controller needs to control the robot end-point in a way that the forces acting at the end-point are negated. For this reason the reference force for all three frames directions must be set to 0 N. This robot behaviour is suitable for freely moving the robot end-point by hand (Figure 4b) in all three directions of the robot work space.

In the third part the students combine the knowledge from the first two parts. The control, where the robot is moving in a circle, is completely the same and only the force controller is slightly different. The robot needs to seek for a contact force of 1 N in  $x$  axis direction of reference frame. During this motion the robot is displaced towards a whiteboard positioned in front of the robot. When the end-point touches the whiteboard, the contact force of 1 N in  $x$  direction is maintained. For a better representation of the movement, the end-point is equipped with a marker pen that draws the end-point path on the whiteboard surface (Figure 4c).

### Theory

The controller that is still suitable

to perform adequately for the project requirements is a proportional controller. The most important is that the students understand how the error between the reference and current control value is used in the control loop.

In addition to understanding the proportional controller principle and using this knowledge to write a program, the students need to define the appropriate reference inputs of the proportional controller. The first part of the project requires the circular movement of the robot end-point in  $yz$  plane of the reference frame. For this purpose should be defined the circular movement as stated by equations (10) and (11):

$$y_r = y_s + r \cdot \sin(\omega \cdot t) \quad (10)$$

$$z_r = z_s + r \cdot \cos(\omega \cdot t) \quad (11)$$

The  $x$  position of the robot end-point is fixed at the starting position  $x_r = x_s$ . Parameters  $r$  and  $\omega$  are pre-defined.

The controller output to the robot system, in our case the xPC Target controller, is a velocity  $v$ . It is calculated by multiplying the position error  $e_p$  between current  $p$  and reference position  $p_r$  and position gain value  $K_p$ .

The proportional controller to control the robot by the force at the end-point in the second part of the project is only slightly different from the first part. The basic difference is the control parameter, which is force and not position. The students need to write a program to calculate the error  $e_f$  between the reference force  $f_r$  and current force  $f$ , measured directly by the force and torque sensor attached to the robot end-point. To move the robot freely in

space the reference force values are set to 0 N.

In the third part of the project students accomplish a circular movement of the robot end-point in  $yz$  plane of the reference frame while maintaining the contact force of 1 N in  $x$  axis direction of the reference frame with the whiteboard placed in 6 front of the robot. The end-point is equipped with a marker pen that draws the end-point trajectory on the whiteboard. This whiteboard can also be rotated to different angles regarding to starting perpendicular orientation to the marker pen. At the beginning the proportional gain of force controller  $K_{pr}$  is set to a low value and when the slope of the whiteboard is not perpendicular to the marker pen, the force control in direction of  $x$  axis of the reference frame is not fast enough. For this reason the students need to increase the gain value. They can observe the real robot end-point behaviour when the gain is too low or too high. When the gain  $K_{pr}$  is set too high the robot becomes unstable and bounces against the whiteboard.

## 6 The survey results

When the laboratory practical projects for Robotics class were being prepared, several goals were specified. It was our aim that the students are motivated and come to the laboratory with enthusiasm. The practical work involves theory related to real-life problems. The projects can be considered also as preparation for examination and are preparing the students for working in a team.

To achieve these goals it was necessary to make use of real industrial robots, to prepare the proper laboratory textbook, to prepare student projects to be of proper difficulty and that the oral examination following each project is well accepted by the students.

At the end of the semester in June 2012 we performed a short survey among the students of Robotics class to assess the effectiveness of the teaching process. The number

of students was 38 and all completed the survey. The survey consisted of seven questions.

**Question 1: "Is it important to perform laboratory practical projects mainly on real industrial robots?"**

**Table 2.** Survey answers in percentage for question 1

a(%)	b(%)	c(%)	d(%)	e(%)	f(%)	g(%)
60,5	<b>84,2</b>	73,7	78,9	60,5	<b>18,4</b>	23,7

**Table 3.** Survey answers in percentage for question 2

a(%)	b(%)	c(%)	d(%)	e(%)	f(%)	g(%)
<b>78,9</b>	<b>10,5</b>	55,3	65,8	63,2	21,1	26,3

**Table 4.** Survey answers in percentage for question 4

a(%)	b(%)	c(%)	d(%)	e(%)	f(%)
21,1	36,8	<b>89,5</b>	15,8	13,2	<b>0,0</b>

This question had two possible answers, *Yes* and *No*. The results showed, that all 38 students agreed that it is of utmost importance to perform the laboratory projects on real industrial robots. The positive answer had also the subquestion "If the answer is *Yes*, why is it important?". The students could choose several answers among several possible:

- To use robotic systems from several manufacturers.
- Real situations enable better insight into the robot system.
- Much more can be learned from real situations.
- Real situations give more experience.
- The knowledge can be used in future professional work.
- Repeating the knowledge acquired at lectures.
- Teamwork habituation.

The results in *Table 2* show that the students did not connect the usage of real industrial robot equipment with lectures (answer f). However, the students believe that working with real robots enables improved insight into the robot systems (answer b), gives more experience (answer d) and much more can be learned from using real equipment (answer c).

**Question 2: "What motivates you in the laboratory practical work?"**

This question was asked to find out which projects are motivating the students the most and which part of the laboratory work must be improved in the future. Several answers could be chosen from the following proposals:

- The laboratory projects are interesting.
- Because at the end of each exercise there is an oral exam.
- The knowledge can be used in future professional work.
- Modern equipment is used.
- Real problems are solved.
- Repeating the knowledge acquired at lectures.
- Teamwork habituation.

The percentage of answer b (*Table 3*) was quite a surprise for us, because we expected that the oral examination will be the only motivation to the students. On the contrary, the students find the projects very interesting (answer a) and also the use of industrial robots (answer d) is very high in ranking.

**Question 3: "Is it suitable that at the end of project written report was replaced by oral exam?"**

Regarding to the previous approach at the laboratory practical work, when the students had to write the final report and defend it, we introduced oral examination after each project. Only answers *Yes* and *No* were possible.

The results showed that all the students found the new approach more suitable than the previous one.

**Question 4: "What do you consider is the main purpose of the oral**

**examination after each project"**

With this question we wanted to find out if the students understand why the oral examination after each project was introduced. Several possible answers could be chosen:

- Development thinking, which can be used in other areas.
- Development of oral expression and communication.
- Checking understanding of the theoretical and practical background of the exercise.
- Repeating the knowledge acquired at lectures.
- Only evaluation.
- None of the above.

In *Table 4* the answers percentages are stated. The answer c stands out with almost 90 %. This percentage made us very pleased, because evaluation of understanding of theoretical and practical background is the goal of the oral examination. It is necessary to mention also the high percentage of answer b, where students find the oral examination as a way for development of oral expression and communication abilities.

**Question 5: "Does the laboratory textbook encourages independent thinking in realization of projects?"**

As it was mentioned, it was our goal to prepare a laboratory textbook [5] which is given freely to the students. It was written and structured in a way to motivate the students to work independently. With this question in the survey we wanted to find out if the goal was successfully reached. The students had to choose one answer among the following possible answers: *Yes*, *I can't tell*, *No*.

The 34 or 89.5 % of the students revealed that the literature was properly written, 2 of them didn't agree at all and 2 students could not take a side.

**Question 6: "Do you think that knowledge acquired from the Robotics lectures helps you at laboratory projects?"**

One of the purposes of educational process is also to relate the lectures as much as possible to practical

projects. This connection was at the top of our goal list when the laboratory projects were prepared and with this question we wanted to find out if the connection is sufficient. The students had to choose one answer among the following possible answers: *Yes, I can't tell, No.*

The results to this question were not as good as we had planned at the laboratory projects preparation. Among 38 students 6 of them did not agree that the theoretical knowledge helped them to perform the laboratory projects. However, 29 of the students appreciated the knowledge, while 3 of them could not take a side.

**Question 7: "Do you think that knowledge acquired from the Robotics lectures helps you at laboratory projects?"**

One of the purposes of educational process is also to relate the lectures as much as possible to practical projects. This connection was at the top of our goal list when the laboratory projects were prepared and with this question we wanted to find out if the connection is sufficient. The students had to choose one answer among the following possible answers: *Yes, I can't tell, No.*

The results to this question were not as good as we had planned at the laboratory projects preparation. Among 38 students 6 of them did not agree that the theoretical knowledge helped them to perform the laboratory projects. However, 29 of the students appreciated the knowledge, while 3 of them could not take a side.

## 7 Conclusion

The main idea, when the laboratory projects were being prepared, was to motivate students to successfully finish their work as independently as possible and to study Robotics with enthusiasm. We prepared interesting projects which almost all result in some robot motions. Furthermore, it was also necessary to include a tight connection with the fundamental knowledge pre-

sented during the Robotics lectures.

The method how the final mark for laboratory practical work is given differs from the past. In the past the students needed to write a report for each project example and defend this report. The past experiences showed, and this is also quoted in the literature [3], that many students have copied the report from hardworking and independent students. This was one of the reasons why the oral examination after each laboratory project was introduced. The initial fear that defending each laboratory project will influence the atmosphere during the laboratory work disappeared over time and this is proven also by the survey results.

The survey that we had performed among the students showed that our teaching and evaluation approach has many advantages. The students are coming to the laboratory much better prepared and motivated and therefore the projects run faster with more questions asked by the students. To achieve this goal it was very important to prepare appropriate laboratory textbook, enabling the students to prepare themselves for individual projects at home and also to use the textbook efficiently during the laboratory projects.

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## Motivacijski laboratorijski projekti pri dodiplomskem predmetu robotika

### Razširjeni povzetek

Študentski laboratorijski projekti so najpomembnejši člen učnega procesa pri študiju tehnike. To še posebej velja za področje robotike. Laboratorijska izkušnja mora študentom nuditi spoznavanje opreme, delovnih navad in tesne povezave med teorijo in prakso. Namen članka je predstaviti motivacijske laboratorijske projekte pri predmetu Robotika, kjer študenti uporabljajo industrijske robote. Predstavljeni projekti so neposredno povezani s predavanji homogenih transformacij, z robotskim modelom in robotskim vodenjem po poziciji in sili. Vsak študent samostojno ali v manjši skupini do treh študentov opravi šest projektov. Članek detajlno opisuje tri študentske laboratorijske projekte.

Prvi je namenjen spoznavanju in predvsem utrjevanju ter razumevanju uporabe homogenih transformacij v praktičnem primeru. Študenti z vajo spoznavajo postopek, ki določi dve homogeni transformacijski matriki, s katerima nato izračunajo lego kamere glede na referenčni koordinatni sistem robota. Ta informacija je ključna za izračunavanje lege objektov (zamaškov) glede na referenčni koordinatni sistem, če so lege objektov zaznavne s pomočjo videokamere oz. znane v koordinatnem sistemu kamere. Po ustreznih matematičnih operacijah študenti poženejo že napisan robotski program, ki zamaške, glede na njihovo lego v koordinatnem sistemu videokamere, pobere in privije na ustja plastenk.

Za razumevanje pojma kinematika študenti opravijo laboratorijski projekt, pri katerem morajo glede na podano skico robota z uporabo metode z vektorskimi parametri določiti geometrijski model robota. Ta model določa lego zadnjega koordinatnega sistema na vrhu robota glede na referenčni koordinatni sistem robota v odvisnosti od spremenljivk njegovih sklepov. Projekt izvajajo za robot Epson PS3.

V sklopu predavanj študenti spoznajo tudi različne načine vodenja robotov. Običajno so industrijski roboti vodeni po poziciji, vendar pa pri enem laboratorijskem projektu spoznajo, da je mogoče robot voditi tudi po sili. Projekt se izvaja na robotu Stäubli RX90, ki ima na vrhu nameščen senzor sile JR3. Z zapisom izredno preprostega proporcionalnega regulatorja, katerega izhod predstavlja hitrost vrha robota glede na bazni koordinatni sistem, študenti realizirajo: vodenje robota po poziciji s kroženjem vrha v eni ravnini, vodenje robota po sili, izmerjeni s senzorjem sile z referenčno silo enako 0 N, ter hibridnim vodenjem (po poziciji in sili), kjer realizirajo risanje kroga na tablo pred robotom, pri čemer je kontaktna sila med pisalom in tablo 1 N.

Na koncu vsakega posameznega laboratorijskega projekta preverimo znanje oz. razumevanje posameznega študenta glede na projekt, ki ga je tisti dan opravljal. Tako vsak študent dobi od 3 do 5 vprašanj, ki se nanašajo neposredno na razumevanje delovanja projekta s stališča teorije kot tudi prakse.

Konec poletnega semestra v šolskem letu 2011/2012, torej po zaključku laboratorijskih projektov, smo med študenti opravili anketo. Ta je pokazala, da so laboratorijski projekti pri predmetu robotika zanimivi in študente motivirajo za delo, pohvalili pa so tudi neposredno povezanost s snovjo predavanj, kar jim pomaga pri utrjevanju snovi za izpit.

**Ključne besede:** robotika, laboratorijski projekti, homogene transformacije, geometrijski model robota, vodenje robota