GOCE DELCEV UNIVERSITY, SHTIP, NORTH MACEDONIA
FACULTY OF ELECTRICAL ENGINEERING

ETIMA 2021

FIRST INTERNATIONAL CONFERENCE

19-21 OCTOBER, 2021

TECHNICAL SCIENCES APPLIED IN ECONOMY, EDUCATION AND INDUSTRY

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ЕЛЕКТРОТЕХНИЧКИ ФАКУЛТЕТ

UNIVERSITY „GOCE DELCHEV" - SHTIP
FACULTY OF ELECTRICAL ENGINEERING

ПРВА МЕЃУНАРОДНА КОНФЕРЕНЦИЈА
FIRST INTERNATIONAL CONFERENCE

ЕТИМА / ETIMA 2021

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PREFACE

The Faculty of Electrical Engineering at University Goce Delcev (UGD), has organized the International Conference ***Electrical Engineering, Informatics, Machinery and Automation - Technical Sciences applied in Economy, Education and Industry-ETIMA*.**
ETIMA has a goal to gather the scientists, professors, experts and professionals from the field of technical sciences in one place as a forum for exchange of ideas, to strengthen the multidisciplinary research and cooperation and to promote the achievements of technology and its impact on every aspect of living. We hope that this conference will continue to be a venue for presenting the latest research results and developments on the field of technology.
Conference ETIMA was held as online conference where contributed more than sixty colleagues, from six different countries with forty papers.
We would like to express our gratitude to all the colleagues, who contributed to the success of ETIMA'21 by presenting the results of their current research activities and by launching the new ideas through many fruitful discussions.
We invite you and your colleagues also to attend ETIMA Conference in the future. One should believe that next time we will have opportunity to meet each other and exchange ideas, scientific knowledge and useful information in direct contact, as well as to enjoy the social events together.

The Organizing Committee of the Conference

ПРЕДГОВОР

Меѓународната конференција ***Електротехника, Технологија, Информатика, Машинство и Автоматика-технички науки во служба на економија, образование и индустрија-ЕТИМА*** е организирана од страна на Електротехничкиот факултет при Универзитетот Гоце Делчев.
ЕТИМА има за цел да ги собере на едно место научниците, професорите, експертите и професионалците од полето на техничките науки и да претставува форум за размена на идеи, да го зајканува мултидисциплинарното истражување и соработка и да ги промовира технолошките достигнувања и нивното влијание врз секој аспект од живеењето. Се надеваме дека оваа конференција ќе продолжи да биде настан на кој ќе се презентираат најновите резултати од истражувањата и развојот на полето на технологијата.
Конференцијата ЕТИМА се одржа online и на неа дадоа свој допринос повеќе од шеесет автори од шест различни земји со четириесет труда.
Сакаме да ја искажеме нашата благодарност до сите колеги кои допринесоа за успехот на ЕТИМА'21 со презентирање на резултати од нивните тековни истражувања и со лансирање на нови идеи преку многу плодни дискусии.

Ве покануваме Вие и Вашите колеги да земете учество на ЕТИМА и во иднина. Веруваме дека следниот пат ќе имаме можност да се сретнеме, да размениме идеи, знаење и корисни информации во директен контакт, но исто така да уживаме заедно и во друштвените настани.

Организационен одбор на конференцијата

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SIMULATION OF AN INDUSTRIAL ROBOT WITH THE HELP OF THE MATLAB SOFTWARE PACKAGE

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Abstract

Robotics is an applied technical science that is a link between machines and computer technology. Robotics includes various branches such as machine design, control and regulation theory, computer programming, artificial intelligence and theory of production. In other words, robotics is an interdisciplinary science that covers the fields of mechanics, electronics, informatics and automation. In this paper we will deal with industrial robots or industrial manipulators. The first part of the paper will explain the basic concepts of industrial manipulators. The different configurations of the industrial manipulators and their working space will be considered. The second (practical) part of this paper will explain the modeling and simulation of the Scara robot in Matlab. The movement of the robot from point to point will be simulated (application in palletizing, spot welding, assembly, etc.).

Keywords: industrial manipulators, modeling and simulation, Scara robot, Matlab,

1.Introduction

Robotics is an applied technical science that is a link between machines and computer technology. Robotics includes various branches such as machine design, management and regulation theory, computer programming, artificial intelligence and production theory. In other words, robotics is an interdisciplinary science that covers the fields of mechanics, electronics, informatics and automation. It deals primarily with the study of machines that can replace humans in the performance of tasks, such as various forms of human physical activity and decision making. The development of robotics is initiated by the desire of man to try to find a replacement for himself, which could be related in his capacity in different applications, taking into account the interaction with the environment around him. They replace man primarily with dangerous, monotonous and difficult jobs. Man is left with work tasks that require more intelligence, knowledge and creativity. In this way, robots contribute to increasing productivity, and at the same time to humanizing work. In all their applications, industrial manipulators perform certain movements to perform their work tasks. The drive system is responsible for the successful execution of the movements of the manipulator, together with the commands that are in accordance with the trajectory of the desired movement. Control the movement of the manipulator end effector requires an accurate analysis of the characteristics of the mechanical structure, actuators and sensors that make up the robotic system of an industrial manipulator. The purpose of such an analysis is to determine the mathematical model of the components of the industrial manipulator. The application of software packages for modeling and simulation in robotics is of increasing importance in the design of robotic systems and the determination of a mathematical model and analysis of the components that make up the industrial manipulator. One of the most commonly used tools for modeling and simulation in robotics is the Robotics Toolbox for Matlab. This software tool enables working with vectors and matrices, homogeneous transformations, solving problems of direct and inverse kinematics, generating the trajectory of motion and the orientation of the robot. In this paper, a DH model of a SCARA robot with four degrees of freedom was developed, based on which a simulation of the robot's movement from point to point was performed. The paper practically demonstrates the capabilities of the Matlab software package with its Peter Corke Robotics Toolbox plugin for modeling, simulation, trajectory generation, and visual representation of the robot and its movement.

2.Robot kinematics

Regardless of the constructive performance of the robot, a way is needed that will fully describe the position and movement of the robot in space. There are two ways to define robot kinematics: Danavit Hartenberg analytical procedure and numerical procedure based on Rodriges formulas. The first method is used to determine the kinematic equations of the robot, while the other method is used to determine the dynamic equations of the robot. There are two basic problems with formulating the kinematics of a robot: forward and inverse kinematic problems. To solve the problems of forward and inverse kinematics, a reference coordinate system is defined which is placed on the base of the robot, based on that reference coordinate system the external coordinates of the robot are determined, ie the position of the robot end effector in (x, y, z) space. Each joint of the robot is joined by a Cartesian coordinate system so that the z-axis of the coordinate system coincides with the axis of rotation. The robot's end effector is accompanied by a coordinate system of the robot tool, so that when solving the robot kinematics, the coordinates are transformed in relation to the reference coordinate system. The internal coordinates of the robot are scalar quantities that describe the position of one segment relative to the other segment of the kinematic pair that make it up. The number of internal coordinates depends on the number of degrees of freedom, ie the number of joints of the robotic manipulator. The internal coordinates are usually denoted by q_i and represent the vector q = $[q_1, \ q_2 \ldots \ . q_n]$. External coordinates describe the position of the robotic manipulator end effector in space relative to the reference coordinate system. The position of the robot's hand is described by the coordinates (p_x, p_y, p_z), and the orientations are described by the Euler angles (r_x, r_y, r_z). Determining the vector of the external coordinates for a given vector of the internal coordinates is called a forward kinematic problem. By changing the internal coordinates, the position of the robot's hand in space changes, ie the external coordinates change. While the reverse process, determining the vector of internal coordinates for a given vector of external coordinates is called the inverse kinematic problem. The first step in solving the direct kinematic problem is to define a symbolic scheme (mathematical model) of the robotic manipulator in relation to the reference coordinate system and to define the zero position of the robotic manipulator. At zero position all the internal coordinates of the robot have a value of zero. The procedure of Danevit and Hartenberg will be explained below. The Danevit and Hartenberg procedure is a simple way to model the joints and segments of a robot and can be applied to any robotic configuration. To model an robotic arm according to the Danavit Hartenberg convention, an appropriate coordinate system is attached to each joint of the manipulator. More specifically, the z-axis and the x-axis are joined while the y-axis is always normal to both axes, but it does not need to be determined because the DH model does not use the y-axis (Figure 1). The connection of the coordinate system to the joints is done as follows:

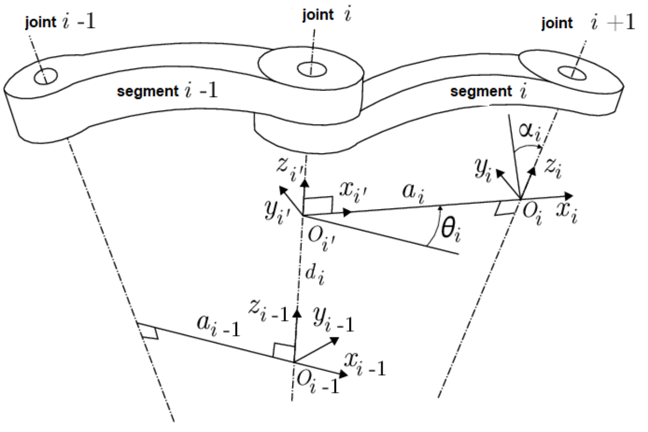

Figure1.DH parameters of kinematic pair of rotary joints

All joints are represented by a z-axis. If the joint is rotational, the z-axis is set in the direction of rotation as a rule of the right hand, while if the joint is translational, the z-axis is set in the direction of the translational movement. z_{n-1} denotes the z-axis associated with the n-th joint, z_n denotes the axis associated with the (n + 1) -th joint, and z_{n+1} denotes the z-axis of (n + 2)-th joint. If the joint is rotational its variable will be the angle of rotation q, about the z-axis, and if the joint is translational its variable will be the length of the segment along the z-axis denoted by d. In the general case, the joints do not have to be parallel or intersecting. As a crescent, their z-axes are generally divergent lines. It is known from geometry that for two lines that are intersecting, there is always a line that is normal to them and represents the shortest distance between the intersecting lines. This normal line is called the common normal line of the intersecting lines and the x-axis of one joint is always set in the direction of the common normal line of its z-axis and the z-axis of the previous joint. Consequently, if a_n is the common normal line between the z_{n-1} axis and the z_n axis, the direction of the x_n axis will be along a_n. Similarly if a_{n+1} is the common normal line between z_n and z_{n+1}, the direction of the x_{n+1} axis will be along a_{n+1}. If two adjacent z-axes are parallel then they have an infinite number of common normal line. In such a case, a joint normal line is chosen that is collinear with the joint normal line of the previous joint. If two adjacent z-axes intersect, they have no common normal line. The x-axis is then set in the direction of the normal line to the plane formed by the two z-axes.

To model any robot configuration according to DH notation and convention we need four parameters:

- Parameter a_i - distance between z_{i-1} and z_i axis along the x_i axis (segment length)
- Parameter d_i - distance along the z_{i-1} axis from θ_{i-1} to the intersection of the x_i and z_{i-1} axes (moving the segment)
- Parameter α_i - the angle between the z_{i-1} and z_i axis, measured around the x_i axis (angle of rotation of the segment)
- Parameter θ_i - the angle between x_i and x_{i-1} ,measured around the z_{i-1} axis (angle of rotation of the segment)

3. Scara robot with four degrees of freedom and DH parameters

The SCARA is a type of industrial robot. The acronym stands for Selective Compliance Assembly Robot Arm or Selective Compliance Articulated Robot Arm. By virtue of the SCARA's parallel-axis joint layout, the arm is slightly compliant in the X-Y direction but rigid in the 'Z' direction, hence the term: Selective Compliant. This is advantageous for many types of assembly operations, i.e., inserting a round pin in a round hole without binding. The second attribute of the SCARA is the jointed two-link arm layout similar to our human arms, hence the often-used term, Articulated (Figure 2).

Figure2.Scara(Selective Compliance Assembly Robot Arm)robot

The type of robot that will be the subject of modeling and simulation in this paper is the Scara robot configuration with four degrees of freedom. The robot that will be modeled is with RRTR configuration, ie seen from the base to the top, it has two rotational, translational and rotational joints. (Figure 3) shows the mathematical model of the Scara robot with associated coordinate systems to the joints according to DH notation. Based on this DH model, the four parameters that we will need to create and model our robot type with the help of a robotics tool in the Matlab environment are determined (Figure 4).

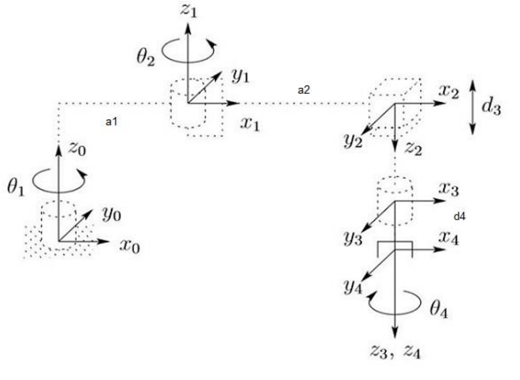

Figure3.Mathematical model of Scara robot with associated coordinate systems to the joints

Зглоб	θ	d	a	α	Нулта q
1	θ_1	0	a_1	0º	0º
2	θ_2	0	a_2	180º	0º
3	0º	d_3	0	0º	0º
4	θ_4	d_4	0	0º	0º

Figure 4.DH parameters for Scara robot with four degrees of freedom

4. Modeling and simulation of Scara robot in Matlab

Creating and modeling our Scara robot involves entering its parameters according to the Danavit Hartenberg notation into .m file that is created using a command from the File-New> Script menu. The modeling of the Scara robot with four degrees of freedom according to the model of (Figure 3) and according to the DH parameters from (Figure 4) is done by setting the dimensions of the segments and the dimensions of the robot tool (Figure 5). In our case a1 is the length of the segment that joins the first and second rotational joints, a2 is the length of the segment joining the second and third (translational) joints, while d4 represents the tool length of the Scara robot.

```
Editor - C:\Users\User\Desktop\семинарска индустриски робот\ptpscara.m*
ptpscara.m*
% Димензии на сегментите и апатот на роботот
a1 = 40;
a2 = 40;
d4 = 10;
```

Figure 5.Enter the dimensions of the robot segments

The next step in modeling the robot is entering the Danavit Hartenberger parameters. We enter the DH parameters with the function L = Link ([Th d a alpha]). Depending on whether the joint is rotational or translational, we add 0 or 1 at the end, if the joint is rotational we add 0, if the joint is translational then we add 1. After entering the DH parameters, we create the serial connection, ie the kinematic chain that makes up the joints and segments of the robot with the SerialLink (L) function (Figure 6), where we can also give the name of the robot, in our case 2RTR Scara.

```
Editor - C:\Users\User\Desktop\семинарска индустриски робот\ptpscara.m
ptpscara.m
%Моделирање на Scara робот со DH параметри
%Ограничувања во зглобовите
L(1) = Link([0 0 a1 0 0]);
L(1).qlim =  pi/180*[-180 180];
L(2) = Link([0 0 a2 pi 0]);
L(2).qlim =  pi/180*[-180 180];
L(3) = Link([0 0 0 0 1]);
L(3).qlim = [0 50];
L(4) = Link([0 d4 0 0 0]);
L(4).qlim =  pi/180*[-360 360];
%Креирање на сериски кинематски панец
bot = SerialLink([L(1) L(2) L(3) L(4)]);
%Име на роботот
bot.name = '2RTR Scara';
```

Figure 6.Enter DH parameters and create Scara robot

The robot modeled in this way can be represented graphically if we give the command bot.plot (q0) in the command window, where q0 = [0 0 0 0] represents the vector of the zero position, ie the initial position of the robot. (Figure 7). A point-to-point movement simulation will be performed on the Scara robot modeled and created in this way. In point-to-point movement, the manipulator moves at discrete points in the workspace, and the trajectory between the points is not important, but the positioning accuracy is important. This mode of motion control is used for discrete operations such as: point finishing, moving objects, palletizing, etc.

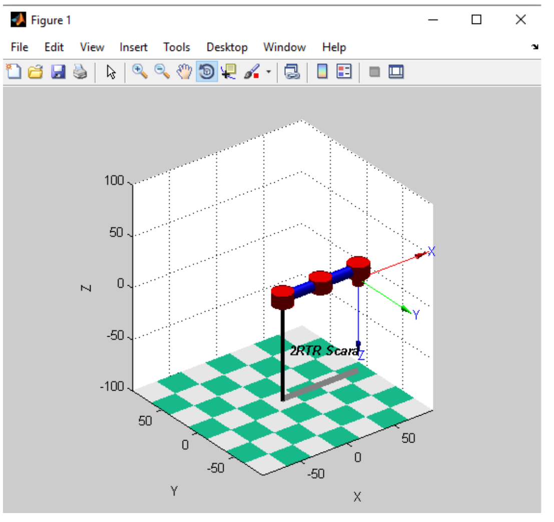

Figure 7.Graphic display of the Scara robot in the initial position

The simulation will be a simple example of positioning the robot in space, ie a circular plate will be given together with the positioning points. The drawing of the plate is done with the help of the plot.circle function, with given coordinates of the plate and the positioning points of the robot in the working space (Figure 8).

Editor - C:\Users\User\Desktop\семинарска индустриски робот\ptpscara.m

ptpscara.m

```
%Координати на работната плоча и точките на дупчење
p0=[-40 35 -40];
p1=[-20 35 -40];
p2=[-60 35 -40];
%Исцртување на работната плоча и точките на дупчење
plot_circle(p0, 40, 'black');
plot_circle(p1, 5, 'black');
plot_circle(p2, 5, 'black');
```

Figure 8.Coordinates and drawing the contour of a plate

The robot in zero position and the contour of the circular plate together with the positioning points are given in (Figure 9).

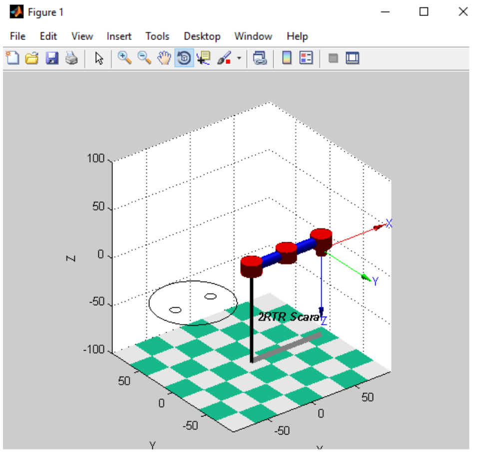

Figure 9. Graphic display of the Scara robot in the initial position and plate

The transformation matrices from the zero position to the points where the robot is to be positioned are given by the function T = transl (p0), where p0 (x, y, z) is a point in space (Figure 10). The transformation matrices have a dimension of 4x4 and represent the position and orientation of the robot in space, for given internal coordinates of the robot joints. The Robotics Toolbox uses the ikine function to determine the inverse kinematic problem.

```
Editor - C:\Users\User\Desktop\семинарска индустриски робот\ptpscara.m*
ptpscara.m*

    %Трансформациони матрици за точките на движење
    T1 = transl(-60, 35, -30);
    T2 = transl(-60, 35, -40);
    T3 = transl(-20, 35, -30);
    T4 = transl(-20, 35, -40);
    %Инверзна кинематика за векторот на внатрешните
    %координати до точките на движење
    q1 = bot.ikunc(T1);
    q2 = bot.ikunc(T2);
    q7 = bot.ikunc(T3);
    q8 = bot.ikunc(T4);
```

Figure 10.Forward and inverse kinematic problem

Point-to-point positioning in the Robotics Toolbox is done using the jtraj function (q0, qf, t). The jtraj function generates the trajectory of the joints or internal coordinates so that the robot is positioned from the starting point q0 to the end point qf during time t (secounds). (Figure 11).

```
Editor - C:\Users\User\Desktop\семинарска индустриски робот\ptpscara.m*
ptpscara.m*

    %Генерирање на траекторија
    %од точка до точка
    q0 = [0 0 0 0];
    q3 = jtraj(q0, q1, 20);
    q4 = jtraj(q1, q2, 30);
    q5 = jtraj(q2, q1, 30);
    q6 = jtraj(q1, q7, 20);
    q9 = jtraj(q7, q8, 30);
    q10 = jtraj(q8, q7, 30);
    q11 = jtraj(q7, q0, 20);
```

Figure 11.Generating trajectory for positioning points

We visualize the simulation with the plot function, for all generated trajectories from the zero position to the points where the Scara robot should be positioned. (Figure 12).

```
Editor - C:\Users\User\Desktop\семинарска индустриски робот\ptpscara.m*
ptpscara.m*

    %Симулација на движењето од точка до точка на Scara робот
    bot.plot(q3, 'workspace', [-100 100 -100 100 -100 100], 'tilesize', 30.0, 'tile1color', [0.1 0.8 0.6], 'jointcolor', 'r', 'jointdiam', 2.5);
    bot.plot(q4, 'workspace', [-100 100 -100 100 -100 100], 'tilesize', 30.0, 'tile1color', [0.1 0.8 0.6], 'jointcolor', 'r', 'jointdiam', 2.5);
    bot.plot(q5, 'workspace', [-100 100 -100 100 -100 100], 'tilesize', 30.0, 'tile1color', [0.1 0.8 0.6], 'jointcolor', 'r', 'jointdiam', 2.5);
    bot.plot(q6, 'workspace', [-100 100 -100 100 -100 100], 'tilesize', 30.0, 'tile1color', [0.1 0.8 0.6], 'jointcolor', 'r', 'jointdiam', 2.5);
    bot.plot(q9, 'workspace', [-100 100 -100 100 -100 100], 'tilesize', 30.0, 'tile1color', [0.1 0.8 0.6], 'jointcolor', 'r', 'jointdiam', 2.5);
    bot.plot(q10, 'workspace', [-100 100 -100 100 -100 100], 'tilesize', 30.0, 'tile1color', [0.1 0.8 0.6], 'jointcolor', 'r', 'jointdiam', 2.5);
    bot.plot(q11, 'workspace', [-100 100 -100 100 -100 100], 'tilesize', 30.0, 'tile1color', [0.1 0.8 0.6], 'jointcolor', 'r', 'jointdiam', 2.5);
```

Figure 12.Simulation of point to point movement

In (Figure 13) you can see part of the simulation of the movement of the Scara robot, from point to point.

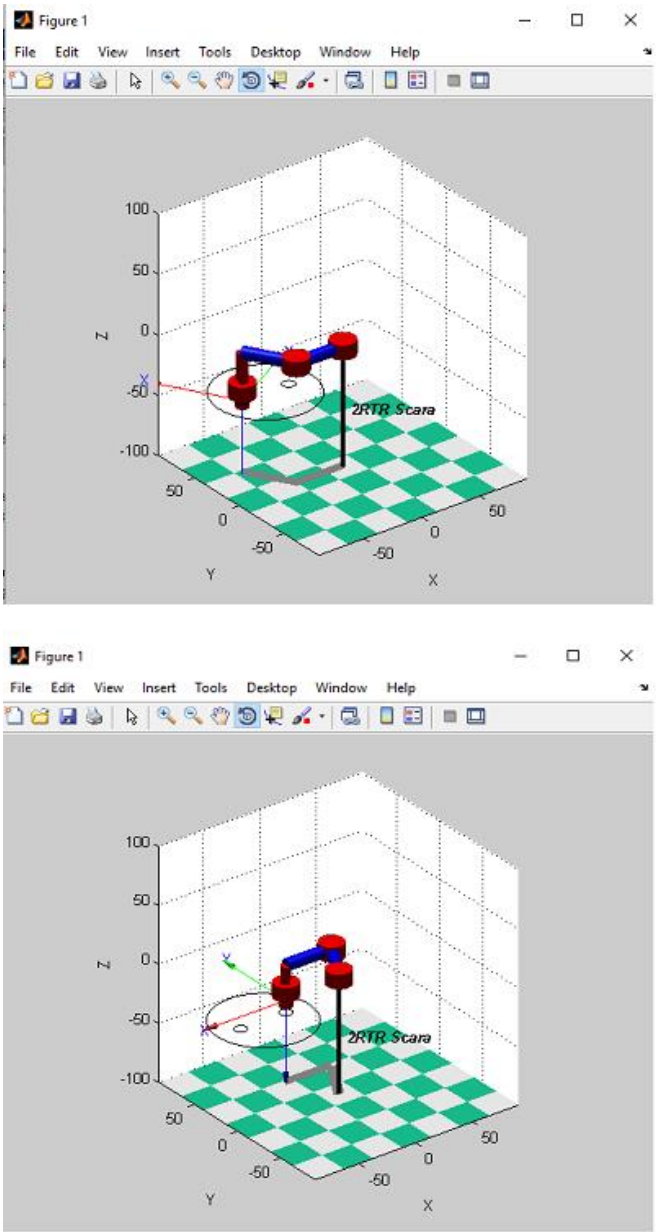

Figure 13.Simulation of Scara robot movement from point to point

4.Conclusion

Industrial production today is almost unthinkable without automation. Industrial manipulators have greatly enhanced automation in industrial plants and raised it to a higher level. Old and slow machines become history over time and are replaced by new modern automated machines and manipulators. Robotic manipulators make the job easier, replacing the men in difficult and dangerous jobs, which makes the men feel more secure in the workplace and his work comes down to observing the technological process.

The first part of the paper will explain the basic concepts of industrial manipulators. The different configurations of the industrial manipulators and their working space will be considered. The second (practical) part of this paper will explain the modeling and simulation of the Scara robot in Matlab. The movement of the robot from point to point will be simulated (application in palletizing, spot welding, assembly, etc.).

Literature

[1] Saso Gelev ”Robotika i avtomatizacija” Univerzitet “Goce Delcev” http://e-lib.ugd.edu.mk/500

[2] Peter Corke “Robotics Toolbox for Matlab”, Release 9 http://www.petercorke.com/RTB/robot.pdf

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[4] Zdenko Kovačić, Stjepan Bogdan, Vesna Krajči “Osnove Robotike” http://www.graphis.hr/news/robotika/robotika_39.pdf