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Investigation of Forward Kinematics Software Program and Control of 3-DOF Manipulator Robot Using a New Developed Geometrical Approach Method for Improvement of Quality Food and Chemical Industries

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Abstract:

The aim of this research is to compute the forward kinematics and control of a robotic arm, which is using in different industries such as food, polymer, pharmaceuticals and chemistry production. Employers in chemical factories sometimes causing some errors during the packaging process, as well as high production costs and time spent on implementation, therefore, it is better to replace this human work with programmable manipulator robot that can be implemented with development of production quality, and also reduce the cost of these operations from the previous one.

In addition, the main advantage of using these manipulators is automating control without losing working time or boredom and quality improvement within chemical industrial lines.

This study had done by using a new developed geometrical approach method to compute forward kinematics problems with a highly accurate result, saving a long time in mathematical calculations, easier and comfort in using for all mechatronics and robotics designers and engineers.

The advantages of this research, is to design and study a forward kinematics of Three Degree of Freedom of two types of robotic arm.

The first type is Revolute-Revolute-Revolute joints 3-DOF (RRR), which using in PUMA manipulator robot.

The second type is Revolute-Revolute-Prismatic joints 3-DOF (RRP), which using in SCARA manipulator robot.

An investigation of forward kinematics software program of 3-DOF manipulator robot was developed to save time and cost. In addition, obtained results can be implemented in food and biotechnology industry, cryogenics and other industries.

Keyword: Control, Food Industries, Chemical Industries, PUMA Robot, SCARA Robot, Optimal Design, Forward Kinematics, Motion, Mechatronics, LabVIEW; SolidWorks.

1. INTRODUCTION

Robot kinematics refers the analytical study of the motion of a robot manipulator. Formulating the suitable kinematics models for a robot mechanism is very crucial for analyzing the behavior of industrial manipulators. There are mainly two different spaces used in kinematics modelling of manipulators namely, Cartesian space and Quaternion space. The transformation between two Cartesian coordinate systems can be decompose into a rotation and a translation. [1]

The control of robot manipulators has been a research area for years and has developed various control strategies. [2, 3, 4]

The food and chemical industries are a challenging yet changing market. Flexibility within these industries is the most sought after property in the modern day production line system. These industries are a rapidly versatile industry driven by customer quality needs and the ability to respond to changes swiftly in the shortest time, at the lowest cost. [5]

Robotic arm with computing of the inverse kinematics and control of a trajectory for a robotic arm, software program of KUKA manipulator robot with order and arrangement of rotary motors due to saving labor cost and machining time. [6]

Software design of inverse kinematics and control of a trajectory for a SCARA manipulator robot which using to choose the optimal path of all obtaining trajectories by select the minimum value of criterion. [7]

Denavit-Hartenberg (1955) method that uses four parameters is the most common method for describing the robot kinematics. Denavit & Hartenberg showed that a general transformation between two joints requires four parameters. These parameters known as the Denavit-Hartenberg (DH) parameters have become the standard for describing robot kinematics. [8]

Introducing an automated adapting system that is flexible, enough to adapt its programming methods automatically seems like in order to satisfy quality requirements. [9, 10]

In this study, the design of an adaptive design controller based on forward kinematics program and LabVIEW using NI-SoftMotion module as a controller is developed on SCARA and PUMA manipulator robots with three degree of freedom 3-DOF. This controller is designed based on connection between LabVIEW and Solidworks programs, where NI-SoftMotion module works to send and receive the data and information of forward kinematic problem.

2. FORWARD KINEMATICS OF ROBOTIC ARM

The robotic arm is composed of a serial chain of rigid links connected to each other by revolute or prismatic joints. Each robot joint location is usually defined relative to the neighboring joint. The relation between successive joints is containing a 4x4 homogeneous transformation matrix that has orientation and position data of robots. Conversion of the position and orientation of robot manipulator end-effectors from Cartesian space to joint space is called as inverse kinematics problem. The corresponding joint values must be computed at high speed by the inverse kinematics transformation. [11]

For a manipulator with n degree of freedom, at any instant of time the joint variable is denoted by $i = \theta(t)$, i = 1, 2, 3 ….....n and position variables by $x_j = x(t)$, j = 1, 2, 3 …....m. The relations between the end-effectors position x(t) and joint angle θ(t)can be represented by forward kinematic equation

$$x(t) = f(\theta(t)) \qquad (1)$$

Where, *f* is a nonlinear continuous and differentiable function.

In this study, instead of conventional techniques by a new technique had done by building a mathematical modelling of a geometric approach of 3-DOF manipulator robot (RRR) as in PUMA robot and (RRP) as in SCARA robot. We defined all design parameters and their relations of others by getting the mathematical equations from geometrical representation, convert these equations in a LabVIEW programming to programming codes and then we can make a check with these results by adding these results for any CAD program as a SolidWorks to sure the realest of these output results.

2.1 Advantages of Proposed Control Program

The proposal of forward kinematics program and LabVIEW using NI-SoftMotion module as a controller has the following advantages:

a- This control technique can be applied to a forward kinematic problem, which is the case of the 3-DOF as in SCARA and PUMA manipulator robots also can be applied for other manipulators.

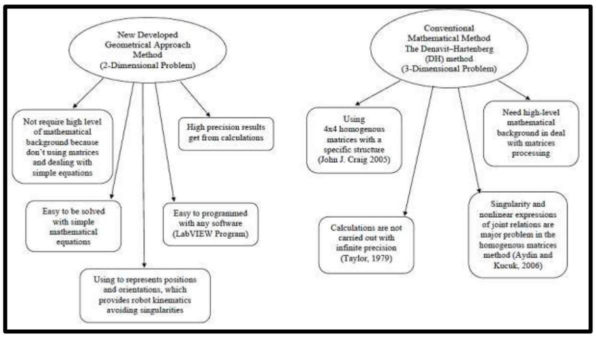
b- The development analysis had done by using a New Geometrical Approach method.

c- It can control most of the robot manipulator systems with knowing their solution, which can be found.

d- The main advantage of this method is that it does not require previous knowledge of the robot dynamics.

e- The proposed control program gives to mechatronics and mechanical design engineers all possible trajectory and can select the suitable trace can be saved a power of manipulator actuators by select a short path.

Different between new developed geometrical approach method and conventional mathematical method is as shown below diagram:



3. PUMA MANIPULATOR ROBOT

In the following figure shown the isometric of 3-DOF (RRR) manipulator robot with three moving axes.

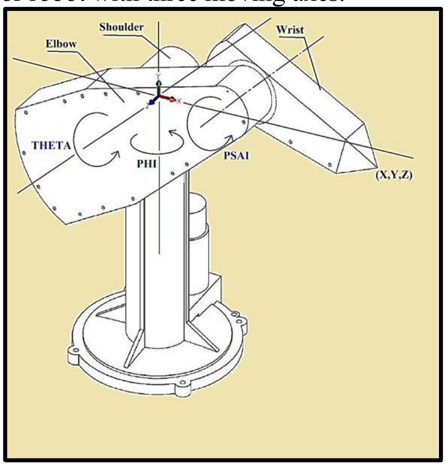


Fig.1 Isometric of 3-DOF (RRR) Manipulator robot with three moving axes.

In this study, we defined the manipulator robot parameters as the following:

x: a displacement of end-effector manipulator along x-axis from the rotation point.
y: a displacement of end-effector manipulator along y-axis from the rotation point.
z: a displacement of end-effector manipulator along z-axis from the rotation point.
d: a shoulder manipulator length.
El: an elbow manipulator length.
Wr: a wrist manipulator length.
L_1: a distance between the rotation point and end-effector, which measured from top plane of a manipulator.

L_2: a projected length of El and Wr in a top plane of a manipulator.
ϕ: an angle between z-axis and d (rotary motor angle of a shoulder), which measured from top plane of a manipulator.
θ: an angle between x-axis and El (rotary motor angle of an elbow) ,which measured from front plane of a manipulator.
ψ: an angle between El and Wr (rotary motor angle of a wrist), which measured from front plane of a manipulator.
A: a projection distance of d a long z-axis, which measured from top plane of a manipulator.
B: a projection distance of L2 a long z-axis, which measured from top plane of a manipulator.
C: a projection distance of d a long x-axis, which measured from top plane of a manipulator.
D: a projection distance of L2 a long x-axis, which measured from top plane of a manipulator.
H: a projection distance of El a long y-axis, which measured from front plane of a manipulator.
G: a projection distance of Wr a long y-axis, which measured from front plane of a manipulator.
E: a projection distance of El a long x\-axis, which measured from front plane of a manipulator.
F: a projection distance of Wr a long x\-axis, which measured from front plane of a manipulator.

Manipulator Robot Parameters Constraints:

1- d > 0, 2- El > 0, 3- Wr > 0, 4- El > Wr

The 3-DOF (RRR) robotic arm's manipulator Workspace as in figure (2):

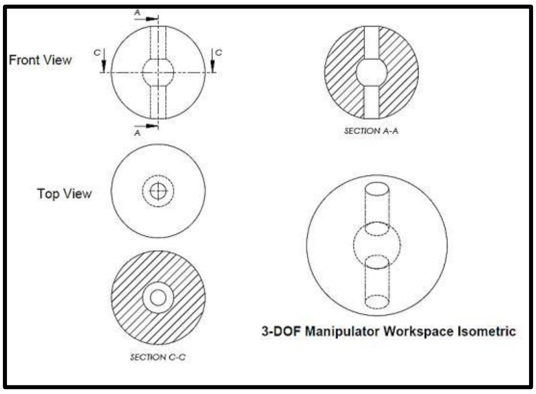


Fig.2 Isometric, Views and Sections of 3-DOF (RRR) Manipulator robot workspace.

In performing tasks, a manipulator has to reach a number of workpieces or fixtures. In some cases, these can be positioned as needed to suit the workspace of the manipulator. In other cases, a robot can be installed in a fixed environment with rigid workspace requirements. Workspace is also sometimes called work volume or work envelope as in figure (2).

The achievable working space looks like a hemisphere, where:

1- The maximum outer diameter will be:

$$2\sqrt{d^2+(El+Wr)^2}$$

2- The minimum inner diameter will be:

$$2\sqrt{d^2+(El-Wr)^2}$$

3- The diameter of vertical hollow cylinder in a hemisphere will be:

$$2d$$

3.1 Control of PUMA Manipulator Robot

The parts of the block diagram are mentioned as follows:

Input Parameters – includes two types: the first is constant as manipulator dimensions (**d**, **El** and **Wr**), and the second is variables as a rotational joint angles (**ϕ**, **θ** and **ψ**) .

Output Parameters – includes the Cartesian Coordinates of end-effector/ tool (**x**, **y** and **z**).

Execute – Controls for the Line Move Function input.

Stop – To exit the loop and stop motion control.

Interface programs LabVIEW and SolidWorks of forward kinematics and control of PUMA 3R robot is as shown in figure (3).

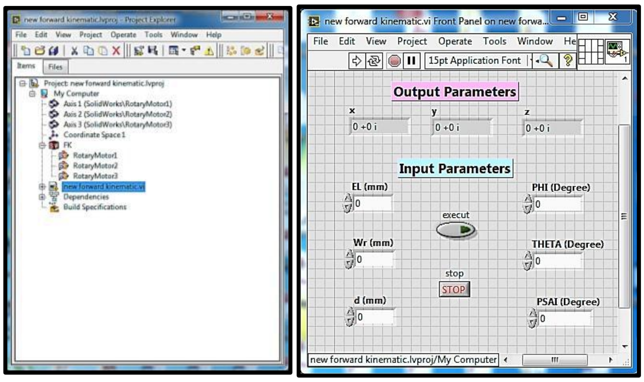


Fig.3 Control Program of 3-DOF (RRR) robot.

Algorithm of Forward Kinematics Programming Design and Control of 3-DOF (RRR) Manipulator robot Using LabVIEW and SolidWorks is as shown below.

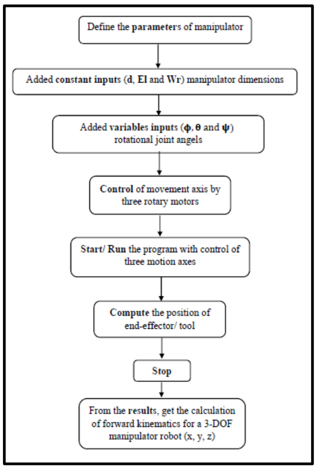


Chart1. Algorithm of Forward Kinematics Programming Design and Control of 3-DOF (RRR) Manipulator robot Using LabVIEW and SolidWorks.

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3.2 Mathematical Model Programming By a New Developed Geometrical Approach of a Forward Kinematics Study of 3-DOF (RRR) Manipulator Robot

$$E = El \times \cos(\theta)$$

$$F = Wr \times \cos[180 - (\theta + \psi)]$$

$$H = El \times \sin(\theta)$$

$$G = Wr \times \cos[(\theta + \psi) - 90]$$

$$L_2 = E + F$$

$$y = H - G$$

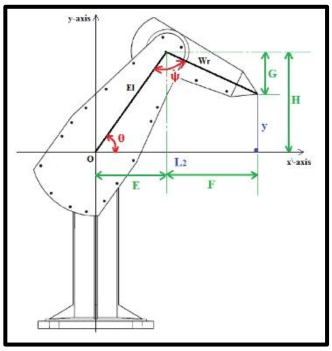

Fig 4. Front View of Representation of Forward Kinematics (RRR) Parameters

$$C = d \times \sin(\phi)$$

$$B = L_2 \times \sin(\phi)$$

$$z = A - B$$

$$x = C + D$$

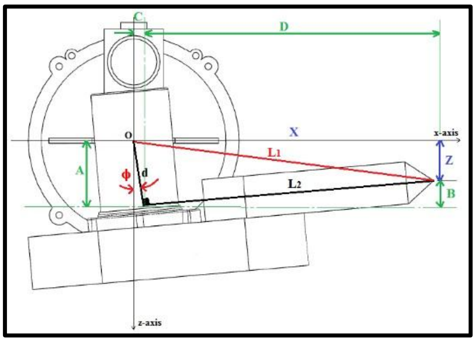

Fig 5. Top View of Representation of Forward Kinematics (RRR) Parameters

3.3 Software Program Design of Forward kinematics of PUMA 3R

The interface of forward kinematics software, which includes the input parameters of manipulator robot (Figure 6).

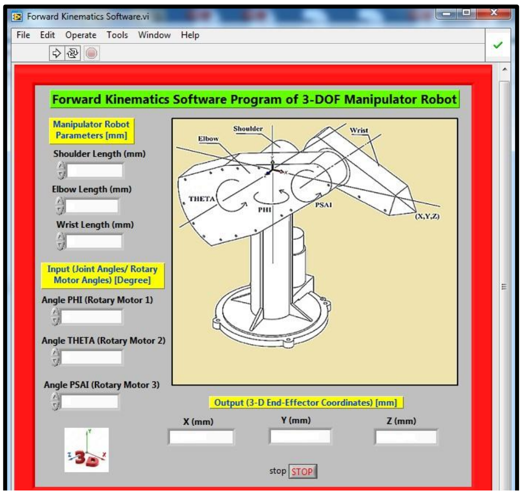

Fig 6. Forward kinematics software of forward kinematics 3-DOF (RRR) manipulator robot.

The input parameters divided into two parts:

a- Constant parameters: as manipulator dimensions: shoulder, elbow and wrist lengths (in mm), these parameters can be changed from robot to another according to its design.

b-Variable parameters: Joint angles **ϕ**, **θ** and **ψ** (Rotary motor angles) (in degree).

The output parameters are: coordinates of end-effector (robot tool) in three dimensions X, Y and Z (in mm).

Table 1. Input parameters of PUMA 3R Robot inverse kinematics and control program.

Manipulator Dimensions (mm)	ϕ (Degree)	θ (Degree)	ψ (Degree)
Shoulder = 127 Elbow = 431.8 Wrist = 351.79	-18. 3837	54.3942	100.174
	161.616	305.606	259.826
	316.456	125.606	-100.174
	136.456	234.394	100.174

Table 2. Output results of a rotational 3-DOF manipulator robot (RRR).

Joint Angles (Degree)	X (mm)	Y (mm)	Z (mm)
ϕ = -18. 3837 θ = 54.3942 ψ = 100.174	500	200	300
ϕ = 161.616 θ = 305.606 ψ = 259.826	-499.999	-199.998	-300.003
ϕ = 161.616 θ = 344.332 ψ = 259.826	-499.999	199.998	-300.003
ϕ = 136.456 θ = 164.332 ψ = -100.174	500	-199.998	300.002

4. SCARA MANIPULATOR ROBOT

In the following figure shown the isometric of 3-DOF (RRP) manipulator robot with three moving axes.

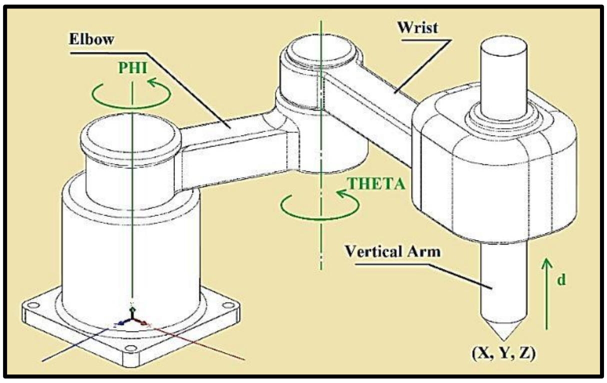

Fig.7 Isometric of 3-DOF (RRP) Manipulator robot with three moving axes.

In this study, we defined the manipulator robot parameters as the following:
x: a displacement of end-effector manipulator along x-axis from the rotation point.
y: a displacement of end-effector manipulator along y-axis from the rotation point.
z: a displacement of end-effector manipulator along z-axis from the rotation point.
L: a vertical arm manipulator length.
El: an elbow manipulator length.
Wr: a wrist manipulator length.

ϕ: an angle between z-axis and El (rotary motor angle of an elbow) ,which measured from top plane of a manipulator.

θ: an angle between Wr and El (rotary motor angle of a wrist), which measured from front plane of a manipulator.

d: a linear vertical displacement of L (linear motor displacement of a vertical arm L) ,which measured from front plane of a manipulator.
A: a projection distance of El a long z-axis, which measured from top plane of a manipulator.
B: a projection distance of Wr a long z-axis, which measured from top plane of a manipulator.
C: a projection distance of El a long x-axis, which measured from top plane of a manipulator.
D: a projection distance of Wr a long x-axis, which measured from top plane of a manipulator.

Manipulator Robot Parameters Constraints:

1- L > 0, 2- El > 0, 3- Wr > 0, 4- Wr > El, 5- $0 \le d \le L$

The 3-DOF (RRP) robotic arm's manipulator Workspace as in figure (8):

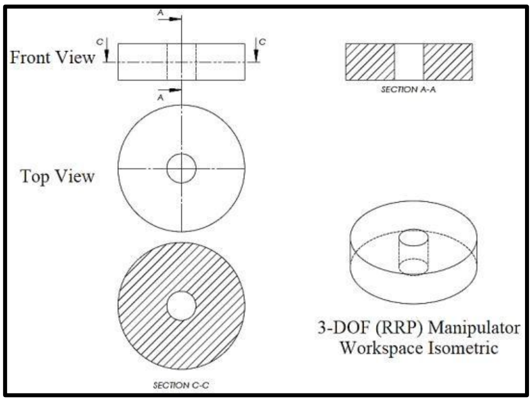

Fig.8 Isometric, Views and Sections of 3-DOF (RRP) Manipulator robot workspace.

In performing tasks, a manipulator has to reach a number of workpieces or fixtures. In some cases, these can be positioned as needed to suit the workspace of the manipulator. In other cases, a robot can be installed in a fixed environment with rigid workspace requirements. Workspace is also sometimes called work volume or work envelope as in figure (8).

The achievable working space looks like a vertical hollow cylinder, where:
1- The maximum outer diameter will be:

$$2(Wr+El)$$

2- The minimum inner diameter will be:

$$2(Wr-El)$$

3- The maximum height of vertical hollow cylinder will be:

$$L$$

4.1 Control of SCARA Manipulator Robot

The parts of the block diagram are mentioned as follows:

Input Parameters – includes two types: the first is constant as manipulator dimensions (**L**, **El** and **Wr**), and the second is variables as a rotational joint angles and a linear displacement (**ϕ**, **θ** and **d**).

Output Parameters – includes the Cartesian Coordinates of end-effector/ tool (**x**, **y** and **z**).

Execute – Controls for the Line Move Function input.

Stop – To exit the loop and stop motion control.

Interface programs LabVIEW and SolidWorks of forward kinematics and control of SCARA (RRP) robot is as shown in figure (9).

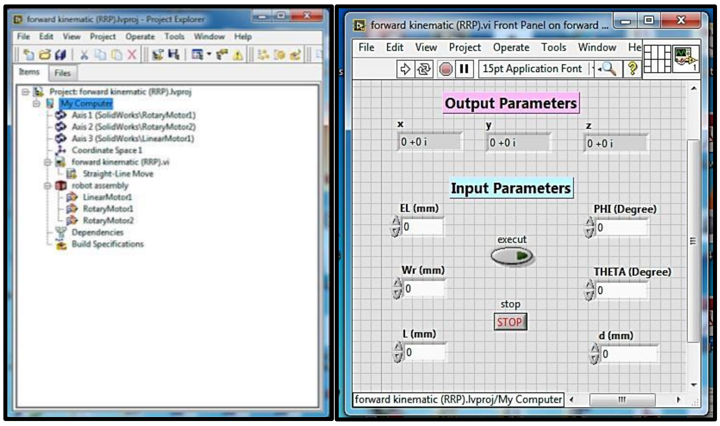

Fig.9 Control Program of 3-DOF (RRP) robot.

Algorithm of Forward Kinematics Programming Design and Control of 3-DOF (RRP) Manipulator robot Using LabVIEW and SolidWorks is as shown below.

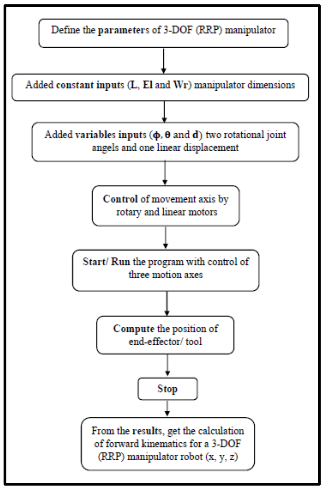

Chart 2. Algorithm of Forward Kinematics Programming Design and Control of 3-DOF (RRP) Manipulator robot Using LabVIEW and SolidWorks.

4.2 Mathematical Model Programming By a New Developed Geometrical Approach of a Forward Kinematics Study of 3-DOF (RRP) Manipulator Robot

$$A = El \times \cos(\phi)$$

$$C = El \times \sin(\phi)$$

$$B = Wr \times \sin[270 - (\phi + \theta)]$$

$$D = Wr \times \cos[270 - (\phi + \theta)]$$

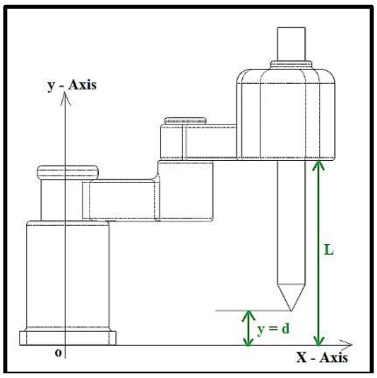

Fig 10. Front View of Representation of Forward Kinematics (RRP) Parameters.

$$x = C + D$$

$$y = d$$

$$z = A + B$$

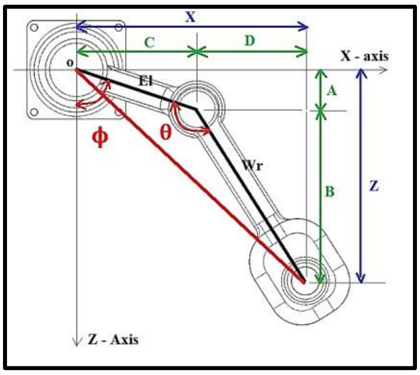

Fig 11. Top View of Representation of Forward Kinematics (RRP) Parameters.

4.3 Software Program Design of Forward kinematics of SCARA (RRP)

The interface of forward kinematics software, which includes the input parameters of manipulator robot (Figure 12).

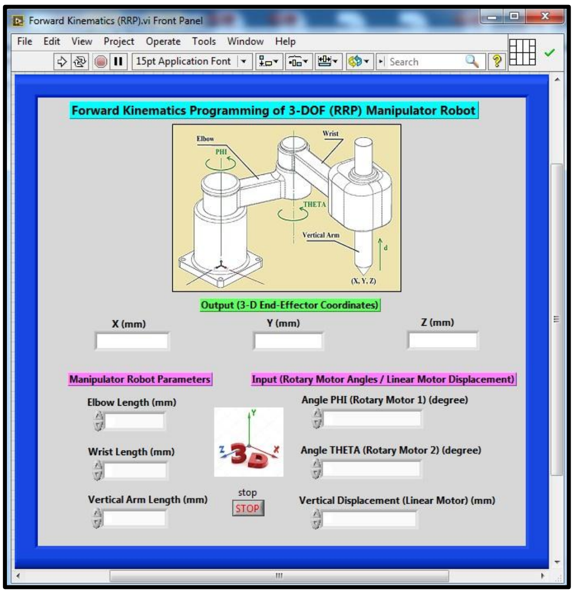

Fig 12. Forward kinematics software of forward kinematics 3-DOF (RRP) manipulator robot.

The parts of the Forward Kinematics Software Program as follows:

Input (Rotation Angels and Linear Displacement of Joints/ Rotary Motors Angles and Linear Motor Displacement) – includes an input variables as a rotational joint angles (**ϕ**, **θ** and **d**).

Manipulator Robot Parameters – includes an input constants as manipulator dimensions (**L**, **El** and **Wr**).

Output (3-D End-Effector Coordinates) – includes the Cartesian Coordinates of end-effector/ tool (**x**, **y** and **z**).

Table 3. Input parameters of SCARA (RRP) Robot inverse kinematics and control program.

Manipulator Dimensions (mm)	ϕ (Degree)	θ (Degree)	*d* (mm)
Elbow = 450 Wrist = 720 Vertical Arm = 670	105.1	80.1	300
	-105.1	-80.1	400
	105.1	-80.1	200
	-105.1	80.1	150

Table 4. Output results of 3-DOF manipulator robot (RRP).

Rotary/Linear Joints (Degree/mm)	X (mm)	Y (mm)	Z (mm)
ϕ = 105.1 **θ** = 80.1 ***d*** = 300	500	300	600
ϕ = -105.1 **θ** = -80.1 ***d*** = 400	-500	400	600
ϕ = 105.1 **θ** = -80.1 ***d*** = 200	130.2	200	-769.8
ϕ = -105.1 **θ** = 80.1 ***d*** = 150	-130.2	150	-769.8

5. DEVELOPMENT OF QULITY FOOD INDUSTRIAL LINES

Manipulator robots can be used in the work of different industries applications such as food, polymer, pharmaceuticals and chemistry production as the following:

5.1 Manipulators in plastic and polymer production

Many applications in this field as robotic injection-Molding, robotic pick and place, and robotic assembly.

Automatic control of robotic arms and improve plastic and polymer production.

5.1.1 Manipulators Increase Safety in Polymer Production

Robotic arms can be used across all areas of plastic and polymer production, including injection-molding, loading and unloading, and pick and place projects.

5.1.2 Protect Employers to higher-value tasks

Dangerous, repetitive tasks in plastics and polymer manufacturing are no longer a challenge. Robot arms can take over dirty, dangerous, and dull jobs to reduce repetitive strain and accidental injuries, while freeing up human operators for higher- value tasks.

5.1.3 Manipulators are ideal for flexible plastics processes

Flexibility is key in automating plastic and polymer manufacturing, since different materials require specific processing setups and temperature ranges. It is fast and easy to move the robot to a new process, giving you the agility to automate almost any task, including those with small batches or fast changeovers in plastic and polymer production and can increase or decrease production without having to adjust staffing levels.

5.2 Manipulators in Pharmaceuticals and Chemistry Production

Maintain high quality with robot arms in food, pharmaceuticals and chemistry production.

5.2.1 Manipulators Take on a Range of Healthcare

Robotics in the pharmaceutical and chemistry industries are performing a wide range of tasks. Robot arms can be used for mixing, counting, dispensing, inspection, and packaging to deliver consistent results. For these critical applications, robots can eliminate human error and possibility of contamination, and increase output and consistent quality.

5.2.2 Stringent Healthcare Industry Specifications

Robots are designed to meet the healthcare industry's stringent requirements for accuracy, precision, and hygiene. Manipulators are provided with a smooth outer housing, which collects almost no dust or deposits.

5.2.3 Manipulators Are Easy in Redeployment for Process

Robotic arms are small enough to fit in nearly any pharmaceutical or chemistry process. Simple programming allows them to be used for a wide range of applications, and programs can be reused for recurrent processes.

6. RESULT

By using the forward kinematics and control program of 3-DOF manipulator robots as in SCARA (RRP) and PUMA (RRR), we can control of the order and arrangement of rotary motors.

We can control the important parameters, which effect on the chemical industry process as trajectory length, working time and used energy.

The main advantages of using the forward kinematics software program and control of 3-DOF manipulator robot which using a new developed geometrical approach method in chemical industries are:

1- Eliminate machine and worker idle time during injection molding processes.
2- Increase output with consistent and ongoing processing.
3- Easily reprogram and redeploy robot arm to other operations as needed.
4- Improve quality and reduce waste.

7. CONCLUSION

This program interface of Forward kinematics can be used for any Three Degree of Freedom as Revolute-Revolute-Revolute joints 3-DOF (RRR) Manipulator robot (such as exist in PUMA 3R Robot) and also Revolute-Revolute-Prismatic joints 3-DOF (RRP) Manipulator robot (such as exist in SCARA Robot), with any dimension lengths.

Manipulator motion can be controlled by order arrangement of actuators to avoid a contact and stick with anybody exist in a manipulator workspace.
The results of the research can be used in food and chemical industries, plastic and pharmaceuticals as a software package to:

1 - Minimizing the number of employers by using the automating robotic system.
2 - Development of the production line productivity.
3 - Increasing of efficiency, quality and accuracy by controlling of the important parameters as trajectory length, working time and used energy.

Overall, this program is a very useful for all mechanical designers and engineers who work in automatic control field because this software saves a lot of time in calculation with respect to another calculations method also can be implemented in mobile devices.

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