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Design and Realization of 3D Simulation System of 6 DOF Robot Manipulator Based on Virtual Universe Pro (Irai) Platform

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Abstract **- Virtual universe pro (Irai) platform is innovative software allowing the creation and simulation of the virtual machines in a 3D-world. Robot manipulators are a series of arms put together with the aid of joints for the purpose of moving objects automatically. In the real world, the performance of the robots depends on so many different factors. Speed, payload weight and precision are the major ones. Though robot manipulators are not a new idea and have already been in present day manufacturing systems they have transformed the existing industries to a new level.**

In this research, the 3D model of the robot manipulator is first developed using SolidWorks-CAD tool. After the robot manipulator is developed, it is imported to virtual universe pro software, there by communicating it with the programmable logic controller (PLC). Inside the platform, the robot manipulator is designed and placed with lathe and milling machine models in a way that shows the material handling process steps of the manipulator. After developing the simulation-capable model, the simulation results are processed for interpretation. Consequently, the model developed has created an interactive visualization that helps to understand the complex dependencies.

The main advantage of this research is that, it is possible to debug PLC programs, and train machine conductors without a real machine. More importantly, it is believed that the teaching-learning environment will be highly enhanced using this simulation-model design.

Keywords: Robot Manipulator; Virtual Universe Pro (Irai); 3D models; PLC ladder program; IP connection

I. INTRODUCTION

In this digital age, new platforms and concepts are being developed for future intelligent manufacturing systems. One amongst them is a virtual reality technology (referred to as VR). In technical terms virtual reality is the term used to describe a three-dimensional, computer-generated environment which can be explored and interacted with by a person. In this paper a 6 DOF robot manipulator is designed and simulated based on virtual universe pro (Irai) platform. The designed manipulator model is the 6 DOF manipulator joints' type. To complete the action; the robot has chassis rotation, vertical arm swing and wrist, elbow, lateral arm pitching and rotary, and gripper. This robot is controlled by PLC program put into the virtual universe pro that uses sensors to guide the end-effector through programmed motions in a workspace. The ultimate use of the manipulator is to achieve the basic concept of intelligent production line through the mobility of material flow. The motion of this robot in the three-dimensional Cartesian space comprises both translational and rotational motions. It's design deals with the position and orientation of several bodies in space.

The model created, after being imported to virtual universe pro (Irai) software, can be simulated in real time, controlled by PLC ladder program of a virtual controller built into the platform with a simple IP connection. The software is suitable to manage and depict the resulting complexity in the analysis of all dependencies in the manufacturing process. The simulation is so interactive that the user can grab and move an object while the simulation is going on.

II. RESEARCH TECHNICAL ROUTE.

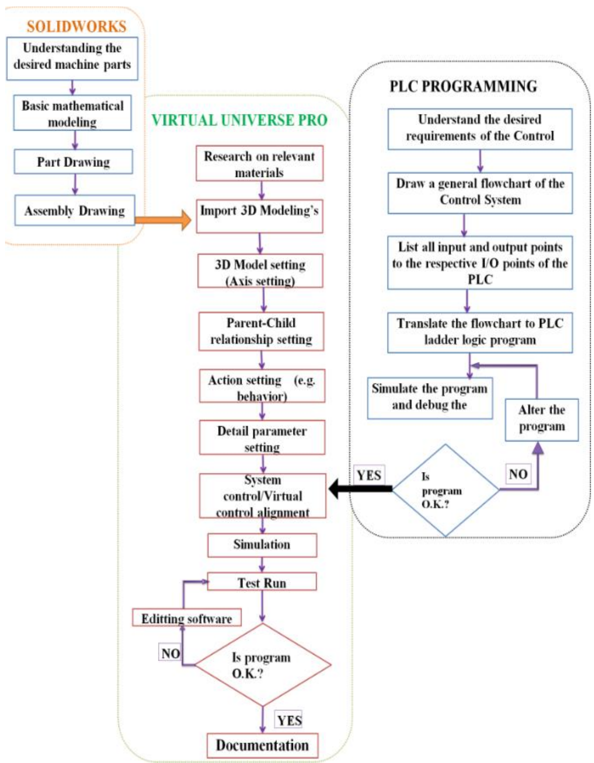

Figure 1. The simulation-model development technical route

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II. BASIC MATHEMATICAL CALCULATIONS AND THE 3D MODEL

A. Kinematics equation of the manipulator

In this research, the establishment of the manipulator system is done based on the principles of Denavit–Hartenberg (DH) method. This method is used to describe manipulator adjacent the kinematic relationship between the two connecting rods, which uses a homogeneous transformation matrix of 4x4 position and posture of the expression of the rigid body. Based on the geometric model on the figure 2, kinematics equation of mechanical arm is established. When dealing with robots, especially in research, it is very essential to calculate the forward kinematics of the robot. In this paper the forward kinematics is calculated based on the following steps.

Step1. The robot manipulator kinematic drawing

It is very important to actually analyze the physical configuration of the robot by drawing its kinematic structure. When sketching the diagrammatic representation of the robot it is also important to put the joint movement direction along the sketch.

Step2. Assigning different joint direction using DH-method

DH-approach is applied on joints and links to determine axis direction as follows. Accordingly, the frame F_i is attached to a link i at joint i+1 in order to create a related kinematics of a local coordinate. The principles applied are the following.

a) The z_i-axis is aligned with the i+1 joint axis

b) The x_i-axis is defined along the common normal between the z_{i-1} and z_i axes, pointing from the z_{i-1} to the z_i axis.

c) The y_i- axis is determined by the right-hand rule.

Step3. Calculating the position of the end-effector

Determining the position of the end effector d_1, through the positions of joints is the ultimate goal of the forward kinematics.

Step4. Calculation of the DH-parameters

Each parameter value is taken with reference to its predecessor joint. It is this parameter value that defines the DH-parameter and later on converted to a matrix form for further analysis.

a) Link length a_i—the distance along the x_i-axis between the z_{i-1} and z_i axes

b) Link twist α_i —the rotation angle along the x_i -axis between the z_{i-1} and z_i axes

c) Joint distance d_i —the distance along the z_{i-1} -axis between the x_{i-1} and x_i axes

d) Joint angle θ_i—the rotation angle about the z_{i-1}-axis between the x_{i-1} and x_i axes

Step 5.Transformation of DH- parameters into matrices

After first calculating the rotation matrix of the robot and the position vector, homogenous transformation is made for the joints.

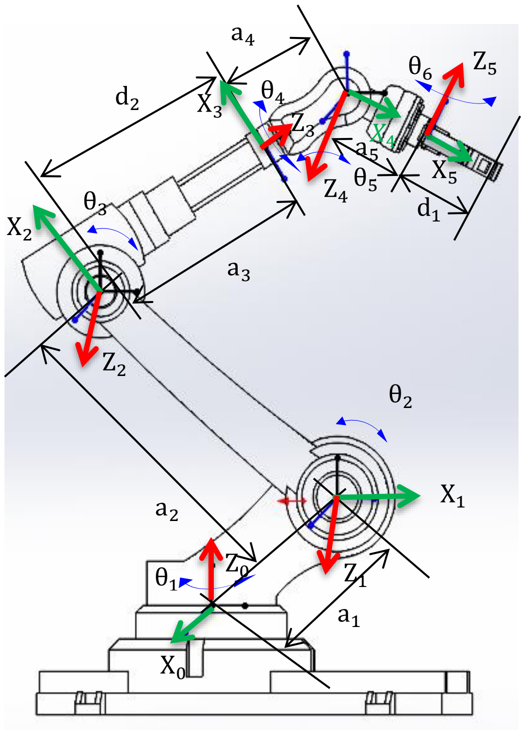

Figure 2. Kinematics of robot manipulator

The DH-parameters of the manipulator are driven as follows.

TABLE 1 DH-PARAMETERS OF THE ROBOT MANIPULATOR

Joint i	θ_i (°)	d_i (mm)	a_i (mm)	α_i (°)
1	θ_1	0	0	90
2	θ_2	0	a_2	0
3	θ_3	d_2	0	90
4	θ_4	0	0	-90
5	θ_5	0	0	90
6	0	d_1	0	0

Where, a_2=757, d_2=a_3=566, a_4=210, a_5=213 and d_1=200

Based on table 1 above the rotation matrix is given us:

$$R_1^0=\begin{bmatrix}C_1 & -S_1 & 0\\ S_1 & C_1 & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}0 & 0 & 1\\ 1 & 0 & 0\\ 0 & 1 & 0\end{bmatrix}=\begin{bmatrix}-S_1 & 0 & C_1\\ C_1 & 0 & S_1\\ 0 & 1 & 0\end{bmatrix}$$

$$R_2^1=\begin{bmatrix}C_2 & -S_2 & 0\\ S_2 & C_2 & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}0 & -1 & 0\\ 1 & 0 & 0\\ 0 & 0 & 1\end{bmatrix}=\begin{bmatrix}-S_2 & -C_2 & 0\\ C_2 & -S_2 & 0\\ 0 & 0 & 1\end{bmatrix}$$

$$R_3^2=\begin{bmatrix}C_3 & -S_3 & 0\\ S_3 & C_3 & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0 & 0\\ 0 & 0 & -1\\ 0 & 1 & 0\end{bmatrix}=\begin{bmatrix}C_3 & 0 & S_3\\ S_3 & 0 & -C_3\\ 0 & 1 & 0\end{bmatrix}$$

$$R_4^3=\begin{bmatrix}C_4 & -S_4 & 0\\ S_4 & C_4 & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}0 & 1 & 0\\ 0 & 0 & 1\\ 1 & 0 & 0\end{bmatrix}=\begin{bmatrix}0 & C_4 & -S_4\\ 0 & S_4 & C_4\\ 1 & 0 & 0\end{bmatrix}$$

$$R_5^4=\begin{bmatrix}C_5 & -S_5 & 0\\ S_5 & C_5 & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0 & 0\\ 0 & 0 & 1\\ 0 & -1 & 0\end{bmatrix}=\begin{bmatrix}C_5 & 0 & -S_5\\ S_5 & 0 & C_5\\ 0 & 1 & 0\end{bmatrix}$$

The homogenous matrix is given as follows:

$$T_1^0=\begin{bmatrix}-S_1 & 0 & C_1 & C_1a_1\\ C_1 & 0 & S_1 & S_1a_1\\ 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\quad T_2^1=\begin{bmatrix}-S_2 & -C_2 & 0 & C_2a_2\\ C_2 & S_2 & 0 & S_2a_2\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

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$$T_3^2 = \begin{bmatrix} C_3 & 0 & S_3 & C_3a_3 \\ S_3 & 0 & -C_3 & S_3a_3 \\ 0 & 1 & 0 & a_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_4^3 = \begin{bmatrix} 0 & C_4 & -S_4 & C_4a_4 \\ 0 & S_4 & C_4 & S_4a_4 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_5^4 = \begin{bmatrix} C_5 & 0 & -S_5 & C_5a_5 \\ S_5 & 0 & C_5 & S_5a_5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_6^5 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The configuration of the end effector T_6^0 is:

$$T_6^0 = T_1^0T_2^1T_3^2T_4^3T_5^4T_6^5 =$$

$$\begin{bmatrix} -S_1 & 0 & C_1 & C_1a_1 \\ C_1 & 0 & S_1 & S_1a_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} -S_2 & -C_2 & 0 & C_2a_2 \\ C_2 & S_2 & 0 & S_2a_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_3 & 0 & S_3 & C_3a_3 \\ S_3 & 0 & -C_3 & S_3a_3 \\ 0 & 1 & 0 & a_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 0 & C_4 & -S_4 & C_4a_4 \\ 0 & S_4 & C_4 & S_4a_4 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_5 & 0 & -S_5 & C_5a_5 \\ S_5 & 0 & C_5 & S_5a_5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_6^0 = \begin{bmatrix} m_x & n_x & o_x & P_x \\ m_y & n_y & o_y & P_y \\ m_z & n_z & o_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where,

$m_x = S_1S_2S_3 - S_1C_2C_3$

$n_x = S_1S_2C_3C_4 + S_1C_2S_3C_4 + C_1S_4$

$o_x = -S_1S_2C_3S_4 - S_1C_2S_3S_4 + C_1C_4$

$P_x = -S_1S_2C_3S_4d_1 - S_1C_2S_3S_4d_1 + C_1C_4d_1 + S_1S_2C_3C_4a_4 + S_1S_2C_3a_3 + S_1C_2S_3C_4a_4 + C_1a_3 - S_1C_2a_2 + C_1a_1$

$m_y = -C_1S_2S_3 -+ C_1C_2C_3$

$n_y = -C_1S_2C_3C_4 - C_1C_2S_3C_4 + S_1S_4$

$o_y = C_1S_2C_3C_4 + C_1C_2S_3C_4 + S_1C_4$

$P_y = C_1S_2C_3C_4d_1 + C_1C_2S_3C_4d_1 + S_1C_4d_1 - C_1S_2C_3C_4a_4 - C_1S_2C_3a_3 - C_1C_{2S_2}S_3C_4a_3 - C_1C_2S_3a_3 + S_1a_3 + C_1C_2a_2 + S_1a_1$

$m_z = C_2S_3 - S_2C_3$

$n_z = C_2C_3C_4 + S_2S_3C_4$

$o_z = -C_2C_3S_4 - S_2S_3S_4$

$P_z = -C_2C_3S_4d_1 - S_2S_3S_4d_1 + C_2C_3C_4a_4 + C_2C_3a_3 + S_2C_3C_4a_4 + S_2S_3a_3$

III. THE CONTROL SYSTEM

A control system is very crucial to ensure the accuracy and smooth transition of a process in intelligent manufacturing processes. It is the command system of the manipulator. The main target of any control system is to control the driving part and make the actuators work as required. In this paper, PLC ladder program inside the program function of the platform is programmed to control the necessary process steps as per the following figure 3.

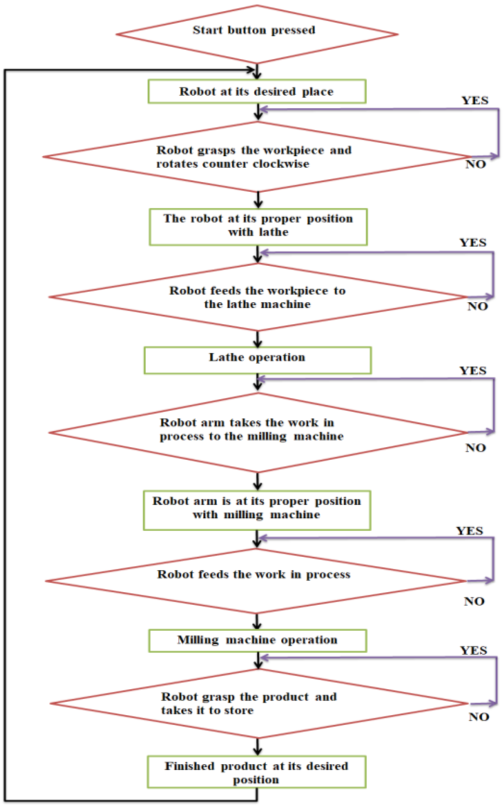

Figure 3. General Activity flow chart of the control system

TABLE 2 THE WORK AND SPEED PARAMETERS OF ROBOT MANIPULATOR

Item		Quantity	
		Designed Capacity	Simulation Value
Axis number		6	
Max. speed of single axis	Axis 1	360°/S	180°/3S
	Axis 2	180°/S	40°/5S
	Axis 3	90°/S	20°/4S
	Axis 4	360°/S	90°/3S
	Axis 5	250°/S	60°/4S
	Axis 6	90°/S	75°/2S
Max. Working Range	Axis 1	±360°	+90°/+270°
	Axis 2	+90° /-90°	-5° /-45°
	Axis 3	0° /-90°	-60° /-80°
	Axis 4	±360°	0° /-90°
	Axis 5	-30°/+220°	30° /90°
	Axis 6	0° /-90°	-15° /-90°
Max. Arm span		1189mm	

IV. DESIGNING OF THE VIRTUAL SIMULATION MODEL

A. Importing the 3D Models into the Virtual Universe Pro (Irai) platform and Parameter Setting

The 3D models of the robot manipulator, the milling machine and the lathe machine are designed using SolidWorks2014 edition, and are first imported to the virtual universe pro (Irai) platform, and then are rescaled and parent-child relationship behavior is set.

B. PLC Programming

PLC ladder programs are written using the ladder program inside the programming function of the software itself.

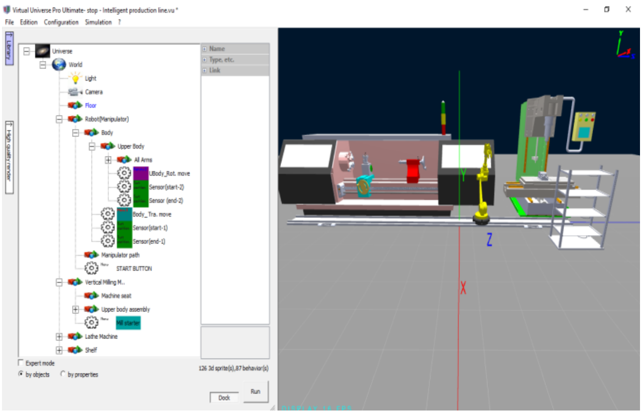

Figure 4. 3D Models imported to Virtual Universe Pro

(Note: The 3D models of lathe machine and vertical milling machine is used to analyze the work motion of the manipulator inside the platform)

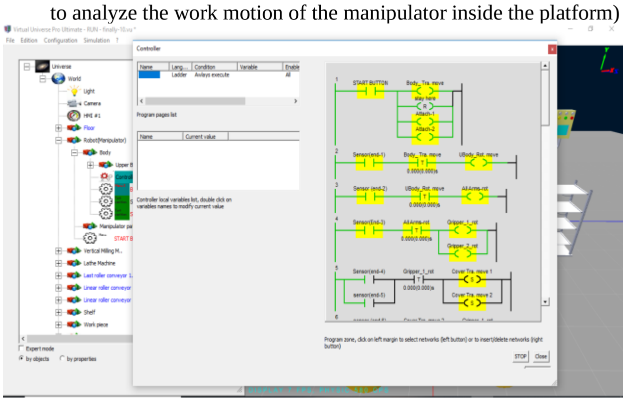

Figure 5. PLC ladder programs of the simulation model

V. VIRTUAL SIMULATION

After setting up all the necessary parameters of Virtual Universe Pro (Irai) software, the simulation is made to run in a 3D virtual environment. From the simulation capable model developed, it was possible to visualize the complex dependencies of the processes and debug the PLC program.

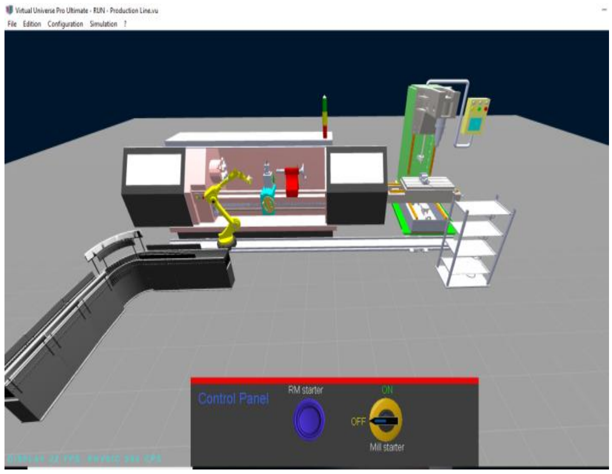

Figure 6. The simulation model picture while on simulation

VI. CONCLUSION

In the contemporary industrial system, the use of 3D-simulation platform aid modification, creation, analysis or optimization of the design. The main aim of this research is the design and the simulation of robot manipulator in a 3D environment with physical simulation based on the virtual universe pro (Irai software) platform. Inside this platform, it was possible to model and emulate the created 3D virtual machine models. After the 3D models are imported and parent-child relationship is set, PLC ladder program loaded to the virtual controller is programmed to control the necessary process steps. After developing a simulation capable model, the simulation results are processed for interpretation. Accordingly, the graphics refresh rate of the simulation model became 22 FPS (Frame Per Second) where the minimum required value is 15FPS. This indicates that the developed simulation model has a good fluidity and visual quality of 3D rendering. The average cycle per second (CPS) of this simulation model can reach up to 620 CPS, where the minimum requirement according to the manual is 100CPS. This is a clear indication of excellent realism of the simulation model.

In this paper, the mechanical part design, PLC programming, and parameter settings are the crucial parts of the simulation model. The application of this research can extend from enhancing the teaching-learning environment to an understanding of the complex dependencies of processes in designing robots. These will, in turn, safe cost and time wastes. It is also believed that it will be a big input for schools with insufficient laboratory equipment's. It can provide a vehicle to expeditiously train the students as per their interests, more easily and economically.

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