

DYNAMIC AND KINEMATIC SIMULATION OF KAWASAKI MANIPULATOR INDUSTRIAL ROBOT USING SOLIDWORKS AND MATLAB SIMMECHANICS

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ABSTRACT

In this paper we present a graphical Human Machine Interface (HMI) with a 3D modeling and simulation of an industrial robot manipulator Kawsaki FS03N with 6 DDF. A direct and inverse geometric model, with kinematics model of robot has been developed. A dynamic robot model is developed with SolidWorks software and Matlab SimMechanics and with a bridge between SolidWorks and Matlab has been developed. The developed models use the actual robot dimensions. The aim of our work that this Human Machine Interface will be used to test different control type before applying to the real robot. Different simulation and reference movements control were performed. Finally, and before opening persepectives on future work we present the results obtained validated the functioning of our interface both SolidWorks software and Matlab.

Keywords: Modeling, 3D simulation, Manipulator robot, Solid Works software, Matlab-Simulink.

1. INTRODUCTION

Robotic science it is a multidisciplinary field mechanical, computer science, electronics. A robot is a machine that can manipulate objects and perform various movements dictated by an easily modifiable program. Program a robot is specify the movement's sequence that will be achieve. Some robots are equipped with "sense". Is a more or less set of measuring instruments and appreciation (camera, thermometer,). to program a robot how choose the more adapted movement with the external conditions. The robots equipped with artificial intelligence devices so that they can deal were unexpected and new complex situations (the robot could gain some "experience"). Robots are mainly used in industry for performing repetitive manipulations, especially when the manufacturing process is subject to frequent changes. The advantage of a robot (robot manipulator) with a contribution-man is his consistency: It can perform the same motion thousands of times in a row without feeling any tiredness (Vibert 1987). Other thing, the robots can be constructed to withstand a basis that would be harmful or fatal to humans (harmful gases, high heat, cold body, radiation,...). A manipulator robot

(with 6 DDF) to flexibility movement and different possible trajectory's and positions (Lallemand 1994). For this raison our work consist to study and to control simulate (in 3Dimention) an industrial robot manipulator kawasaki FS03N (Kawasaki 2003), with the development of a human-machine interface.

2. MANIPULATOR ROBOT KAWASAKI FS03N

The FS03 is a compact multi-purpose robot from the Kawasaki F series (Kawasaki 2003). Weighing just 3 kg, it is designed as a portable model at the smaller end of the range. Despite its size, the FS03 is an advanced 6-axis arm and boasts the highest speed in its class. Launched in 2005, the FS03 retains the compact form of its predecessors but has improved speed and acceleration/deceleration characteristics and significantly reduced cycle times. Whether placed on the floor, suspended from the ceiling or mounted on the wall (Option), the FS03 exhibits excellent freedom of movement, tailoring its acceleration and deceleration speeds to both load weight and robot position for optimum performance in all situations. The FS03 is ideal as an industrial robot for demanding tasks such as assembly, handling and inspection of small components. Standard equipment includes AS high-level robot language and the ultra-compact D70 fully digital controller. The FS03 brings robot technology one step closer to humankind. The various robot arm elements are: The base (A), the shoulder (B), the arm (C), the elbow (D), the forearm (E) and wrist (F) (figure 1).

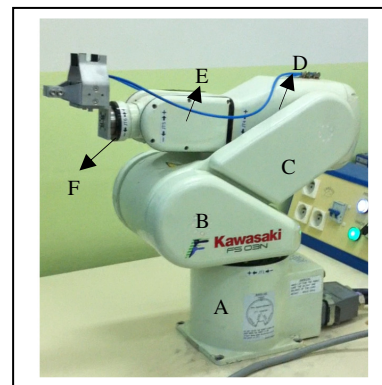


Figure 1: Kawasaki FS03N robot

Three main axes and three wrist axes deliver 6-axis performance (figure 2). The arm can be located in the desired work space and the tool location can be set, allowing greater freedom when locating peripheral equipment. The arm turning axis (JT1) and the wrist axes (JT4, 5, 6) have superior high-speed operation and feature the highest speed specifications in their class. Cycle time is very short (Cycle time: 0.4 ± 0.5 sec*), and high reliability and high precision ensure that they can withstand the most stringent operating conditions of industrial robots(Ijeoma 2012)(Tuna 2001).

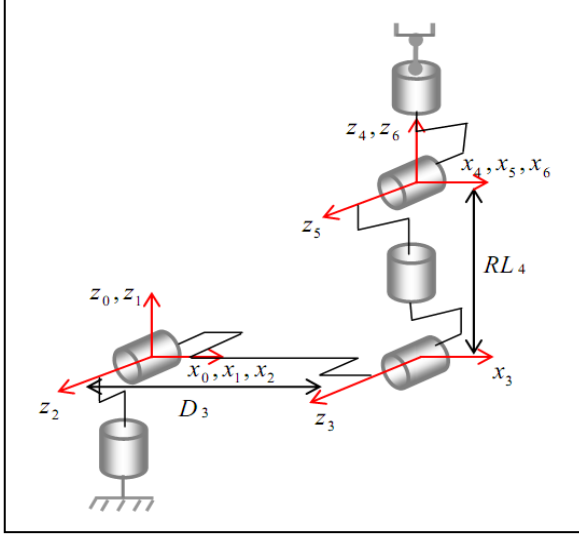


Figure 2: Axis Position.

Ideal for a variety of operating spaces: floor mount, wall mount or ceiling mount. Wiring and conduits for tool sensors are built - in inside the arm for easy operation. The utilization of absolute encoders eliminates the need to zero the unit when powering up. There is no need to worry about gravity induced interference with other equipment when the power is turned off as all six axes are broken. (Kawasaki 2003). Some specification (characteristics) of robot is illustrated in the following table:

Table 1: Kawasaki FS03N robot Specifications.

Specifications	FS03N		
Arm type	Articulated		
Degrees of Freedom	6 Axes		
Maximum Payload	3kg		
Axis Works envelope	axis	Max. Stroke	Max. Speed
	JT1	$\pm 160^\circ$	360°/S
	JT2	$+150^\circ \sim -60^\circ$	250°/S
	JT3	$+120^\circ \sim -150^\circ$	225°/S
	JT4	$\pm 360^\circ$	540°/S
	JT5	$\pm 135^\circ$	225°/S
	JT6	$\pm 360^\circ$	540°/S
Max. linear speed		6.000 mm/s	
Moment and Moment of inertia	Axis	inertia	inertia
	JT4	5.8N.m	0.12 kg.m ²
	JT5	5.8N.m	0.12 kg.m ²
	JT6	2.9N.m	0.03 kg.m ²

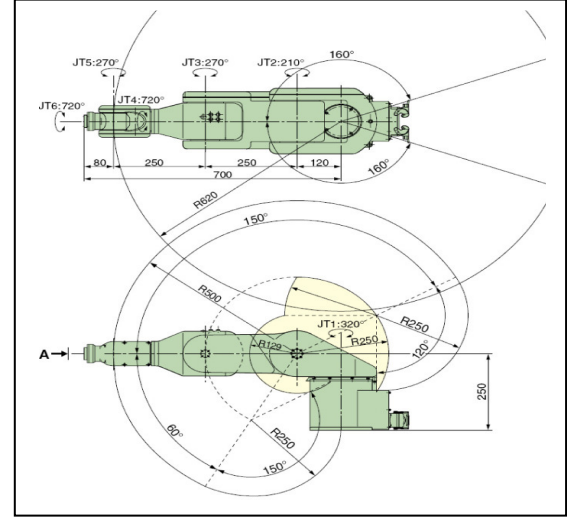


Figure 3: Motion Range & Dimensions of robot.

3. DIRECT GEOMETRIC MODEL

The direct geometric robot model is used to calculate the operational coordinates giving the position of the end-effectors based on joint coordinates. It used also to determine the configuration (position, orientation) end-effector of a robot according to the links configuration. This model is based on the determination of transformation matrix T_6^0 between R_0 and R_6 (Tuna 2000) (John 1989). The direct geometric robot parameters are illustrated in the following table:

Table 2: Direct geometric robot parameters.

J	σ_j	α_j	d_j	θ_j	r_j
1	0	0	0	θ_1	0
2	0	$-\pi/2$	0	θ_2	0
3	0	0	D3	θ_3	0
4	0	$\pi/2$	0	θ_4	RL4
5	0	$-\pi/2$	0	θ_5	0
6	0	$\pi/2$	0	θ_6	0

The homogeneous transformation matrix of the robot is:

$$T_1^0 = \begin{bmatrix} C1 & -S1 & 0 & 0 \\ C1 & S1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} T_0^1 = \begin{bmatrix} C1 & -S1 & 0 & 0 \\ C1 & S1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$T_2^1 = \begin{bmatrix} C2 & -S2 & 0 & d_2 \\ 0 & 0 & 1 & 0 \\ -S2 & -C2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$T_1^2 = \begin{bmatrix} C2 & -S2 & 0 & -C2.d_2 \\ -S2 & -C2 & 1 & -S2.d_2 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$T_3^2 = \begin{bmatrix} C3 & -S3 & 0 & d_3 \\ S3 & C3 & 1 & 0 \\ 0 & 0 & 0 & r_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

$$T_2^3 = \begin{bmatrix} C3 & S3 & 0 & -d_3 \cdot C3 \\ -S3 & C3 & 0 & S2 \cdot d_2 \\ 0 & 0 & 0 & -r_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

$$T_4^3 = \begin{bmatrix} C4 & -S4 & 0 & 0 \\ 0 & 0 & -1 & -r_4 \\ S4 & C4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

$$T_3^4 = \begin{bmatrix} C4 & 0 & S4 & 0 \\ -S4 & 0 & C4 & 0 \\ 0 & -1 & 0 & -r_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (7)$$

$$T_5^4 = \begin{bmatrix} C5 & -S4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -S5 & -C5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (8)$$

$$T_4^5 = \begin{bmatrix} C5 & 0 & -S5 & 0 \\ -S5 & 0 & C5 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (9)$$

$$T_6^5 = \begin{bmatrix} C6 & -S6 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ S6 & C6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (10)$$

$$T_5^6 = \begin{bmatrix} C6 & 0 & S6 & 0 \\ -S6 & 0 & C6 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (11)$$

Finally:

$$T_5^6 = T_1^0 * T_2^1 * T_3^2 * T_4^3 * T_5^4 * T_6^5 \quad (12)$$

$$= \begin{bmatrix} s_x & n_x & a_x & 0 \\ s_y & n_y & a_y & 0 \\ s_z & n_z & a_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} A_6^0 & p_6^0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (13)$$

$$s_x = C_1 \cdot (C_{23} \cdot (C_4 \cdot C_5 \cdot C_6 - S_4 \cdot S_6) - S_{23} \cdot S_5 \cdot C_6) - S_1 \cdot (S_4 \cdot C_5 \cdot C_6 + C_4 \cdot S_6) \quad (14)$$

$$s_y = S_1 \cdot (C_{23} \cdot (C_4 \cdot C_5 \cdot C_6 - S_4 \cdot S_6) - S_{23} \cdot S_5 \cdot C_6) - C_1 \cdot (S_4 \cdot C_5 \cdot C_6 + C_4 \cdot S_6) \quad (15)$$

$$s_z = S_{23} \cdot (C_4 \cdot C_5 \cdot C_6 - S_4 \cdot S_6) + C_{23} \cdot S_5 \cdot C_6 \quad (16)$$

$$n_x = C_1 \cdot (-C_{23} \cdot (C_4 \cdot C_5 \cdot C_6 + S_4 \cdot S_6) + S_{23} \cdot S_5 \cdot C_6) + S_1 \cdot (S_4 \cdot C_5 \cdot S_6 - C_4 \cdot C_6) \quad (17)$$

$$n_y = S_1 \cdot (-C_{23} \cdot (C_4 \cdot C_5 \cdot C_6 + S_4 \cdot S_6) + S_{23} \cdot S_5 \cdot C_6) + C_1 \cdot (S_4 \cdot C_5 \cdot S_6 - C_4 \cdot S_6) \quad (18)$$

$$n_z = -S_{23} \cdot (C_4 \cdot C_5 \cdot C_6 + S_4 \cdot S_6) + S_{23} \cdot S_5 \cdot C_6 \quad (19)$$

$$a_x = -C_1 \cdot (C_{23} \cdot C_4 \cdot S_5 + S_{23} \cdot C_5) + S_1 \cdot S_4 \cdot S_5 \quad (20)$$

$$a_y = -S_1 \cdot (C_{23} \cdot C_4 \cdot S_5 + S_{23} \cdot C_5) + C_1 \cdot S_4 \cdot S_5 \quad (21)$$

$$a_z = -S_{23} \cdot C_4 \cdot S_5 + C_{23} \cdot C_5 \quad (22)$$

$$p_x = -C_1 \cdot (S_{23} \cdot RL_4 + C_2 \cdot D_3) \quad (23)$$

$$p_y = -S_1 \cdot (S_{23} \cdot RL_4 + C_2 \cdot D_3) \quad (24)$$

$$p_y = C_{23} \cdot RL_4 + S_2 \cdot D_3 \quad (25)$$

Avec $C_{23} = \cos(\theta_2 + \theta_3)$ et $S_{23} = \sin(\theta_2 + \theta_3)$

4. INVERSE GEOMETRIC MODEL

If we try to find all possible configurations for a joint position and orientation data an inverse geometric model (IGM) can meet this need. Knowing that for the serial manipulator type, the development of (IGM) is a very difficult and complex issue, where it must reverse a system of nonlinear equations which is not trivial. Nevertheless, and according to the structure of the manipulator robot, there are various methods for solving the IGM in an explicit form. In our case with the manipulator robot Kawasaki FS03N used in industry, the Paul methods can give the solutions of IGM in explicit form (Paul 1981), (Lallemant 1994). Hence we obtain the following solutions:

$$\theta_1 = \text{atan}_2(p_x, p_y); \theta_2 = \text{atan}_2(S_2, C_2) \quad (26)$$

With:

$$S_2 = \frac{Y \cdot Z - \xi \cdot X \cdot \sqrt{X^2 + Y^2 + Z^2}}{X^2 + Y^2} \quad \text{and} \quad C_2 = \frac{X \cdot Z - \xi \cdot X \cdot \sqrt{X^2 + Y^2 + Z^2}}{X^2 + Y^2},$$

$$\xi = \pm 1.$$

$$B_1 = P_X \cdot C_1 + P_Z \cdot S_1; X = -2 \cdot P_Y \cdot D_3;$$

$$Y = -2 \cdot B_1 \cdot D_3 \quad (27)$$

$$Z = (RL_4)^2 - (D_3)^2 + (P_Z)^2 + (B_1)^2 \quad (28)$$

$$\theta_3 = \text{atan}_2\left(P_Z \cdot S_2 - B_1 \cdot C_2 + \frac{D_3}{RL_4}, -B_1 \cdot S_2 + \frac{P_Z \cdot C_2}{RL_4}\right) \quad (29)$$

$$\theta_4 = \text{atan}_2(a_x \cdot S_1 - a_y \cdot C_1, -C_{23} \cdot (C_1 a_x + S_1 a_y) - a_z \cdot S_{23}) \quad (30)$$

$$\theta_4 = \theta_4 + \pi; \quad \theta_5 = \text{atan}_2(S_5, C_5) \quad (31)$$

With :

$$S_5 = -C_4 \cdot [C_{23} \cdot (C_1 a_x + S_1 a_y) + S_{23} \cdot a_z] + S_4 \cdot (S_1 a_x - C_1 a_y) \quad (33)$$

$$C_5 = -S_{23} \cdot [C_1 a_x + S_1 a_y + C_{23} \cdot a_z] \quad (34)$$

$$\theta_6 = \text{atan}_2(S_6, C_6) \quad (35)$$

With :

$$S_6 = -S_4 \cdot [C_{23} \cdot (C_1 s_x + S_1 s_y) + S_{23} \cdot s_z] - C_4 \cdot (S_1 s_x - C_1 s_y) \quad (36)$$

$$C_6 = -S_4 \cdot [C_{23} \cdot (C_1 n_x + S_1 n_y) + S_{23} \cdot n_z] - C_4 \cdot (S_1 n_x - C_1 n_y) \quad (37)$$

$$\begin{aligned} C_1 &= \cos(\theta_1), S_1 = \sin(\theta_1), C_4 = \cos(\theta_4), \\ S_4 &= \sin(\theta_4) \end{aligned} \quad (38)$$

5. INVERSE KINEMATIC MODEL

The inverse kinematics model (IKM), it positions a joint, and generates the joints Parents configuration required to achieve the desired position. Hence an inverse kinematics problem is therefore to find a robot joints configuration in the robot skeleton for positioning a hinge according to a direction and a translation defined at the beginning. The inverse kinematics model (IKM) describes the speed of operational coordinates with joint speeds (yin 2011), (Megahed 1991).

$$\dot{X} = J(q) \cdot \dot{q} = \begin{bmatrix} V_n \\ w_n \end{bmatrix} \quad (39)$$

$J(q)$: Jacobian matrix ($m \times n$), equal $\frac{\partial X}{\partial q}$;

V_n : Translation speed of "O_n" . Its equal derivative of 0P_n vector;

w_n : Rotation speed of R_n [9]

For our case (robot FS03N) we must calculating the basic Jacobian matrix.

$$\dot{X} = \begin{bmatrix} V_n \\ w_n \end{bmatrix} = J_n \cdot \dot{q} = J_n \cdot \dot{O} \quad (40)$$

We noted :

$$\begin{aligned} &\begin{cases} V_{k,n} = (a_k \wedge L_{k,n}) \dot{q}_k \\ w_{k,n} = a_k \cdot \dot{q}_k \end{cases} \\ \Rightarrow &\begin{cases} V_n = \sum_{k=1}^n V_{k,n} = \sum_{k=1}^n (a_k \wedge L_{k,n}) \dot{q}_k \\ w_n = \sum_{k=1}^n w_{k,n} = \sum_{k=1}^n a_k \cdot \dot{q}_k \end{cases} \end{aligned} \quad (41)$$

With:

K : index k^{th} joint of the robot;

$V_{(k,n)}$ and $w_{(k,n)}$: translational and rotation speed;

$L_{(k,n)}$ denotes the original vector O_k and extremity vector O_n ;

a_k : unit vector along the Z_k axis of the articulation k .

Each column of the matrix J_6^i is expressed like following:

$$j_{6,k}^i = \begin{bmatrix} -P_{6y}^k s_k^i + P_{6x}^k n_k^i \\ a_k^i \end{bmatrix} \quad (42)$$

6. ROBOT KAWASAKI (FS03N) MODEL IN SOLIDWORKS :

Using a 3D computer aided design (CAD) software allowed us to model, simulate and make the data management and processes of system. Many 3D software has been developed by Dassault Systems like Catia, ENOVIA, DELMIA, Simula, Exalead and 3DVIA, Solidworks and other.

Various functions can be realization with each different software. We opted to use solidworks since our goal is create a link with Matlab-Simulink software and then control simulate laws develop. SolidWorks is CAD software "Computer aided design". It has been

developed in 1993 and Bought in 1997 by Dassault Systèmes. SolidWorks is design automation software and in this software, you sketch ideas and experiment with different designs to create 3D models. It's used by students, designers, engineers, and other professionals to produce simple and complex parts, assemblies, and drawings (Alejandro 2007). Our robot consists of six segments and a mass attached to the terminal member. With real demotion of each segments we obtained perfect robot reproduction. The various robot segments before and after assembly are illustrated in the following figure:

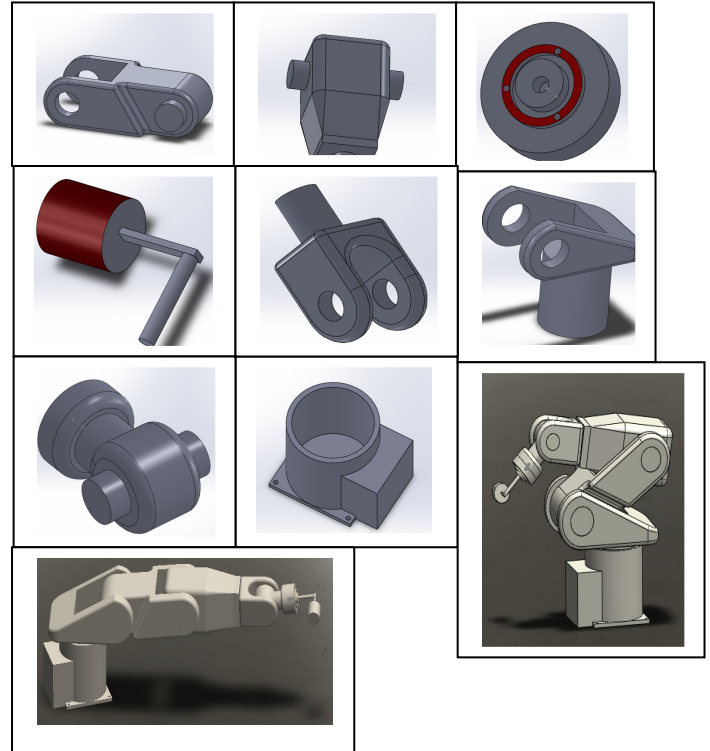


Figure 4: Various robot segments.

7. SIMULATION

3D simulation of the robot kawasakiFS03N) is constructed Malab-Simulink with simmechanics block library (Kalapyshina, 2014). The System (robot) is represented by the following blocks: the body, joints, constraints, and force. The SimMechanics block library provided us the tools to formulate and solve motion equations of complete mechanical system.

We used a bridge between solidworks_matlab with same adaptations (Simmechanics 2007), (Matlab 2010) to operate the robot model that we designed with solidworks. The Simulink modeling then appears:

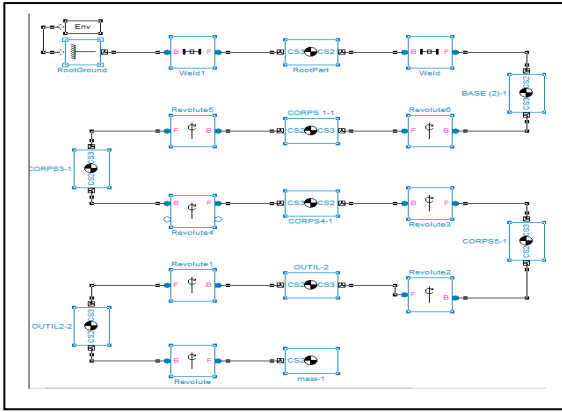


Figure 5: Block diagram of robot Kawasaki (FS03N) model.

With Ctrl+D we obtained volume robot model

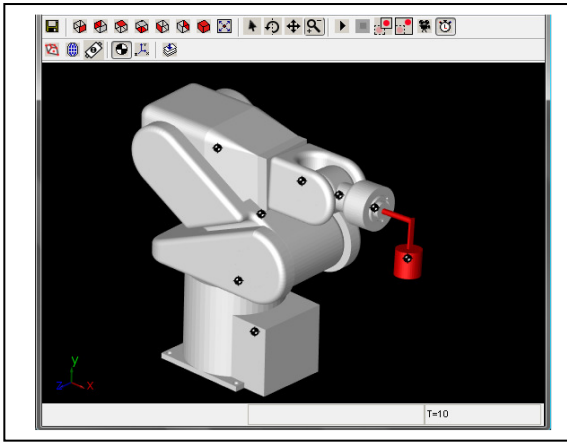


Figure 6: dynamic robot model

The results show that 3D robot model is very close to the real robot (Kawasaki FS03N).

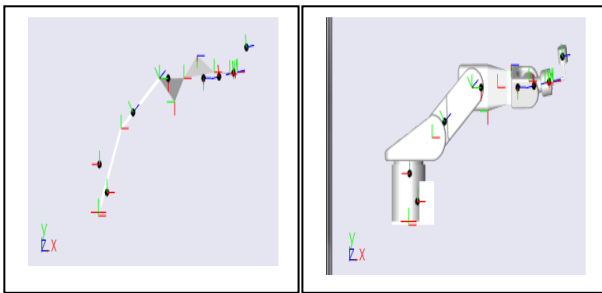


Figure 7: Robot model in simulink and solidworks.

To simplify the simulation we have blocked all robot joints except the terminal element and after we applied a simple control signal.

A block diagram of the robot with the actuator and the sensor is illustrated in the following figure:

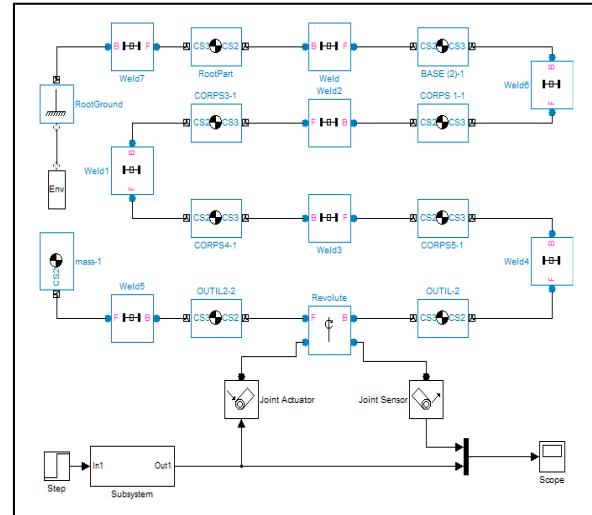


Figure 8: Control diagram block

The results obtained (Figure) illustrated the position of terminal element in four different positions.

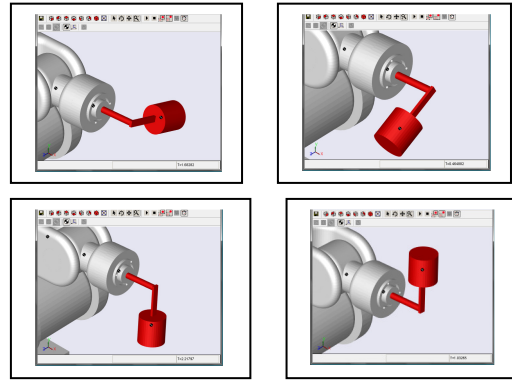


Figure 9: End effectors movement

With direct and inverse geometrical models of robot Kawasaki (FS03N) we created a 3D simulation to apply commands on the terminal element (end effectors). We chose the following simulation parameters:

- The reference mark coordinates $R_0(x_0, y_0, z_0)$.
- The operational coordinates (initial position of the end effector) (x_f, y_f, z_f) .
- The desired end effector position (x_d, y_d, z_d) .

To a reference mark:

$x_0=0$	$y_0=0$	$z_0=0$	
$x_d=100$	$x_d=200$	$x_d=100$	$x_d=100$
$y_d=100$	$y_d=200$	$y_d=100$	$y_d=100$
$z_d=0$	$z_d=0$	$z_d=0$	$z_d=100$

The results are illustrated in the following figures:

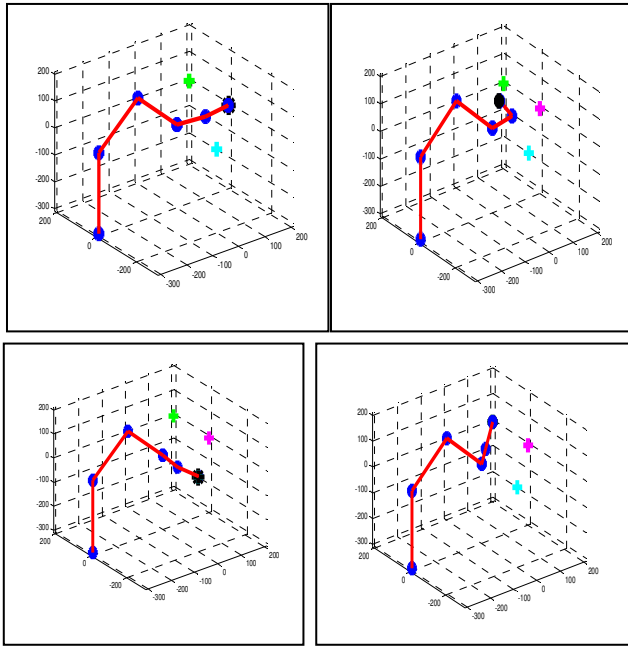


Figure 10: operational coordinates.

The following figures illustrate the comparison obtained results between Matlab model simulation and SolidWorks model software:

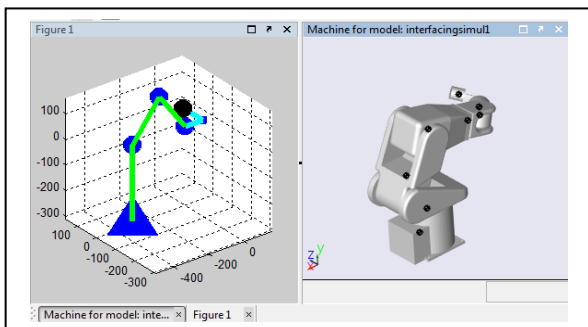


Figure 11: Matlab-Solidworks simulation with different position.

CONCLUSION

This work aimed to study and 3D simulates manipulator robot kawasaki (FS03N) and create a GUI to ease human machine interaction with control tested applied in robot. We can note that our work can be used for all simulation control work in 3D with real constraints for all industrial robots have the same type as Kawasaki FS03N. We have presented different mathematical model of the robot (forward geometric, inverse geometric, kinematics and dynamics). These models are used to simulate the robot in 3D using Matlab and SolidWorks in the same time. From the obtained results we noted that the simulations (Matlab and under solidworks) are almost identical, which will allow us to develop further control laws and improve the GUI. In

the second time compared the obtained results with experimentation results.

REFERENCES

- Yin F., Wang Y.N, Wei S.N.g, 2011., Inverse kinematic solution for robot manipulator based on electromagnetism-like and modified DFP Algorithms. Journal Acta Automatica Sinica, ScienceDirect, Vol.37, No.1, pp.74-82
- Ijeoma W., Tarig F., Al-Assadi H M A A, Mahmud I., 2012. Implementation of Industrial Robot for Painting Applications. Procedia Engineering, vol. 41, pp.1329 – 1335
- Megahed, S.M. 1991. Topological and kinematical study of tree structure robot manipulators: Symbolic computation technique. Journal Robotics and Autonomous Systems, Vol. 7, pp. 27-35.
- Tuna B., Kemal M.Ö, Sahir Arikan M.A, Murat Baykurt H., 2001. A kinematic structure-based classification and compact kinematic equations for six-dof industrial robotic manipulators. Journal Mechanism and Machine Theory, Vol.36, pp.817-832.
- Tuna B., Kemal M.Ö, Sahir Arikan M.A, Murat Baykurt H., 2000. A method of inverse kinematics solution including singular and multiple configurations for a class of robotic manipulators. Journal Mechanism and Machine Theory, Vol.35, pp.1221-1237.
- John J. Addison-Wesley C., 1989. Introduction to Robotics Mechanics and Control, 2th edition, Publishing Company, pp. 450.
- Khalil .W, Dombre .E., 2002, Modeling, Identification & Control of Robots. Hermes Penton Science, pp. 480.
- Lallemant J.-P., Zeghloul, S. 1994. Robotique. Aspects fondamentaux, Masson 1994, pp. 312.
- Vibet, C. 1987. Robots. Principes et contrôle, , Ellipses, pp. 207
- Kalapyschina, I.I, Perechesova, A.A, Nuzhdin, K.A, Musalimov, V.M, Zamoruev, G.B., 2014. Modeling of Mechatronic Systems in Matlab (Simulink / Simmechanics). Proceedings of the 26th European Modeling and Simulation Symposium, 10-12 September, Bordeaux, France
- SimMechanics2, 2007. User's Guide MATLAB & SIMULIK, The MathWorks, September 2007 Online only Revised for Version 2.7 (Release 2007b)
- MATLAB®, 2010. Creating Graphical User Interfaces, September 2010 Online Only Revised for MATLAB 7.11 (Release 2010b).
- Kawasaki robot Manual, 2003. Kawasaki Heavy Industries, Ltd.90206-1034DEF. pp.371
- Alejandro R., 2007. Beginner's Guide to SolidWorks 2007. Schroff Development Corporation. pp.46
- Paul R-P., 1981. Robot Manipulators: Mathematics, Programming and Control. M.I.T Press, ISBN: 026216082X, pp. 292.