Arm Robot Manipulator Design and Control for Trajectory Tracking; a Review

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***Abstract*—Arm robot manipulator heavily applied in industries ranging from welding, pick-and-place, assembly, packaging, labeling, etc. Trajectory planning and tracking is the fundamental design of an arm robot manipulator. The trajectory is set and determined to satisfy a certain criterion effectively and optimally. Optimization of robot trajectory is necessary to ensure the good quality product and to save energy, and this optimization can be provided by the right modeling and design. This paper presents a review study of arm-robot manipulator design and control for trajectory tracking by investigating the modeling of an arm robot manipulator starting from kinematics, dynamics and the application of the more advanced methods. The idea of this paper comes from the popularity of inverse kinematics among students.**

***Index Terms*—Arm robot manipulator; industrial robot; trajectory generation; trajectory tracking.**

I. INTRODUCTION

Robotics and other autonomous systems have been taking an important role in industries and domestic. Robots are machines that have the ability to sense and carry on the assigned test without fatigue. A robot can be fully autonomous and semi-autonomous. Most applied robots are fully autonomous and suffer some issues regarding its properties. Therefore, researchers keep on finding the most efficient and effective way of perfecting autonomous robots applied in industries and finding the most efficient methods for those robots. Arm robot manipulators are designed to replace humans in typical industrial environments that involves dull, dirty, and dangerous environment. Although it is still arguable whether arm robot manipulators are ready to substitute humans, the new revolution of industry, industry 4.0, is already here to prove that a factory needs minimum numbers of human where most of the industrial task are automatically conducted by robots [1] [2].

Arm robot manipulator application in industries ranging from welding, pick-and-place, assembly, packaging, labeling, etc. The commonly applied configurations are SCARA, articulated, cartesian and delta robot. Robot arm manipulator consists of links and joints, and design of links and joints has important roles in controlling robot's trajectory. At the last joint of the robot, an end-effector is attached, and the position of end-effector is an important factor for producing good quality products in industries. The term manipulation refers to operations conducted by the robot including picking and placing an object, grasping, releasing, interaction with the applied environment and transporting objects within it working space.

Trajectory planning and tracking are one of the fundamental issues in the design of a robot manipulator. The trajectory is set and determined to satisfy a certain criterion effectively and optimally. There are two approaches for arm robot manipulator trajectory tracking [3], by using forward and/or inverse kinematics [4]- [14] in calculating desired joint space, and considering robot dynamics in workspace [14]- [18].

Optimization of robot trajectory is necessary not only to ensure a good quality product but also to save energy used by reducing actuator force, and motion time. Energy saving is important since this type of robot is continuously therefore even a small percentage is matter. The application of PID controller is not enough for optimizing robot trajectories, a further method has to be conducted by applying artificial intelligence such as Fuzzy Logic Controller (FLC) [21]- [23], Neural Networks (NN) [24]- [26], the combination of FLC and NN [27] [28] [29], and Genetic Algorithm (GA) [30] [31].

This paper presents a review study of arm-robot manipulator design and control for trajectory tracking. it investigates the modeling of arm-robot starting from kinematics and dynamics, and the possibility of applying artificial intelligence in creating more effective and efficient system. The idea comes from the famous application of inverse kinematics among students, therefore this paper would like to compare and show method with more advanced method than inverse kinematics in designing and controlling an arm robot manipulator since kinematics ignores the existence of dynamics in joints such as vibration, friction etc.

II. KINEMATICS OF ARM ROBOT MANIPULATOR

Kinematics is the science that considers the motion of an object (robot) without cares for the cause of that motion. Kinematics studies the position, velocity, acceleration, and other higher derivatives of position with respect to time. Therefore, the study of kinematics refers to all geometrical and time-based properties of motion [33].

An arm robot manipulator is a set of links connected by joints, the lowest part is called the based, and the end

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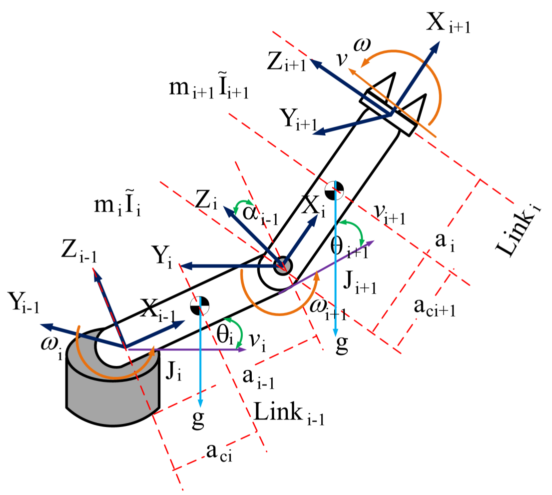

Fig. 1: 2 DOFs revolute arm robot manipulator links

part is called end-effector. The number of joints and how it moves define the degree of freedom (DOF). The joints are characterized as revolute or prismatic joints. Fig. 1 shows 2 DOF robot consists of all revolute joints. A typical applied in industries robot has 5 or 6 joints. In this paper, the kinematics and dynamics are derived from 2 DOF (fig. 1) for the sake of simplicity.

The notations given in fig.1 are

- X_{i-1}, X_i, X_{i+1}, Y_{i-1}, Y_i, Y_{i+1}, Z_{i-1}, Z_i, Z_{i+1} are manipulator coordinate frames.
- a_{i-1}, a_i, a_{i+1}, are the link length, $\alpha_{i-1}, \alpha_i, \alpha_{i+1}$, are the link twist, d_i is the link offset, and θ_i and θ_{i+1} are the joint angles.
- J is robot's Jacobian matrix; J_i is link's Jacobian matrix.
- v_i is link's translational velocity and ω_i is link's rotational velocity.
- m_i is link's mass.
- $\tilde{I}_i$ is link's inertia
- a_{ci} is the length from link's center of gravity to link's end.
- g is gravitational force.

A. Forward Kinematics

There are 2 approaches in calculating the position and orientation of the end-effector, with geometrical approach and algebraic approach. The most applied method, algebraic approach, is by using Denavit-Hartenberg (DH) convention that uses four basic parameters [32]. The distance from Z_{i-1} to Z_i measured along X_{i-1} is a_{i-1}, the angle between Z_{i-1} and Z_i measured along X_i is α_{i-1}, the distance from X_{i-1} to X_i measured along Zi is d_i and the angle between X_{i-1} to X_i measured about Z_i is θ_i [33]. DH representation of fig. 1 is given in table I.

The transformation matrices from base to end-effector is given by

TABLE I: DH-representation

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	a_0	0	θ_1
2	0	a_1	0	θ_2

$$
{}^{i+1}_{i}\mathrm{T} = \begin{bmatrix} c_{\theta_i} & -s_{\theta_i}c_{\alpha_i} & s_{\theta_i}s_{\alpha_i} & a_i c_{\theta_i} \\ s_{\theta_i} & c_{\theta_i}c_{\alpha_i} & -c_{\theta_i}s_{\alpha_i} & a_i s_{\theta_i} \\ 0 & s_{\alpha_i} & c_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{1}
$$

Therefore, the forward kinematics of n-DOF with n-joints is calculated from the base (0) of the robot to the end-effector (n) and given by the matrix

$$
{}^{0}_{n}\mathrm{T} = {}^{0}_{1}\mathrm{T}\,{}^{1}_{2}\mathrm{T} \ldots {}^{n-1}_{n}\mathrm{T} \tag{2}
$$

Based eq. 2, the transformation matrix of 2 DOFs manipulator shown in fig. 1 can be written as

$$
{}^{0}_{1}\mathrm{T} = \begin{bmatrix} c_1 & -s_1 & 0 & a_0c_1 \\ s_1 & c_1 & 0 & a_0s_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad {}^{1}_{2}\mathrm{T} = \begin{bmatrix} c_2 & -s_2 & 0 & a_1c_2 \\ s_2 & c_2 & 0 & a_1s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \tag{3}
$$

$$
{}^{0}_{2}\mathrm{T} = \begin{bmatrix} c_{12} & -s_{12} & 0 & a_0c_1 + a_1c_{12} \\ s_1 2 & c_{12} & 0 & a_0s_1 + a_1s_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{23} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{4}
$$

where $r_{k,j}$ is the rotational elements and k and $j = 1,2,3$. $r_{k,j}$ is calculated using inverse kinematics. The maximum considered DOF is 6DOF, otherwise, it is a redundant robot which kinematics will be different.

From eq. 4, robot's position is

$$
\begin{aligned} p_x &= a_0c_1 + a_1c_{12}, \\ p_y &= a_0s_1 + a_1s_{12}. \\ p_z &= 0 \end{aligned} \tag{5}
$$

If all of the coordinate frames in fig. 1 are removed and only the base is consider, robot zero position is $p_x = a_0 + a_1$.

B. Inverse Kinematics

There are 2 methods to transform a manipulator in Cartesian space into Joints space where the actuators work, namely, geometric and algebraic. For manipulator given in fig. 1, the geometric solution is the easiest way to find inverse kinematics. In this approach, the manipulator is considered in 2D, therefore the considered positions are only p_x and p_y, therefore from eq. 4, robot's position is

$$
\begin{aligned} p_x &= a_1c_1 + a_2c_{12}, \\ p_y &= a_1s_1 + a_2s_{12}, \end{aligned} \tag{6}
$$

By summing the square of p_x and p_y, θ_2 is obtained as follow

$$p_x^2+p_y^2=a_0^2\left(c_1^2+s_1^2\right)+a_1^2\left(c_{12}^2+s_{12}^2\right)+2a_0a_1\left(c_1c_{12}+s_1s_{12}\right), \tag{7}$$

where based on trigonometric law, $c_{12}=c_1c_2-s_1s_2$, $s_{12}=s_1c_2+c_1s_2$, and $c_1^2+s_1^2=1$. Hence, eq. 7 can be written as

$$p_x^2+p_y^2=a_0^2+a_1^2+2a_0a_1c_2, \tag{8}$$

and from eq. 8

$$c_2=\frac{p_x^2+p_y^2-a_0^2-a_1^2}{2a_0a_1}. \tag{9}$$

Since $c_1^2+s_1^2=1$, then

$$s_2=\sqrt{1-\left(\frac{p_x^2+p_y^2-a_0^2-a_1^2}{2a_0a_1}\right)^2}. \tag{10}$$

From eq. 9 and 10, there are 2 possible solutions for θ_2, that are

$$\theta_2=A\tan 2\left(\pm\sqrt{1-\left(\frac{p_x^2+p_y^2-a_0^2-a_1^2}{2a_0a_1}\right)^2},\frac{p_x^2+p_y^2-a_0^2-a_1^2}{2a_0a_1}\right). \tag{11}$$

By revisiting and multiplying eq. 7 with c_1 and s_1

$$\begin{aligned} c_1p_x+s_1p_y&=a_0\left(c_1^2+s_1^2\right)+a_1c_2\left(c_1^2+s_1^2\right),\\ -s_1p_x+c_1p_y&=a_1s_2\left(c_1^2+s_1^2\right), \end{aligned} \tag{12}$$

$$\begin{aligned} c_1p_x+s_1p_y&=a_0+a_1c_2,\\ -s_1p_x+c_1p_y&=a_1s_2. \end{aligned} \tag{13}$$

By combining eq. 13,

$$c_1\left(p_x^2+p_y^2\right)=p_x\left(a_0+a_1c_2\right)+p_ya_1s_2. \tag{14}$$

Therefore,

$$\begin{aligned} c_1&=\frac{p_x\left(a_0+a_1c_2\right)+p_ya_1s_2}{p_x^2+p_y^2},\\ s_1&=\sqrt{1-\left(\frac{p_x\left(a_0+a_1c_2\right)+p_ya_1s_2}{p_x^2+p_y^2}\right)^2}. \end{aligned} \tag{15}$$

Finally, the two possible solutions for θ_1 are given by

$$\theta_1=A\tan 2\left(\pm\sqrt{1-\left(\frac{p_x\left(a_0+a_1c_2\right)+p_ya_1s_2}{p_x^2+p_y^2}\right)^2},\frac{p_x\left(a_0+a_1c_2\right)+p_ya_1s_2}{p_x^2+p_y^2}\right). \tag{16}$$

Calculating inverse kinematics with the geometric method is very cumbersome, and more DOFs will result in a more cumbersome calculation. Another method is algebraic, by expanding the DH convention, however, for 2DOFs, it is easier with the geometric method.

The position of end-effector shown in fig. 1 is given by eq. 5 and the relationship between joints and end-effector is given by

$$\begin{bmatrix} v\\ \omega \end{bmatrix}=\dot{q}. \tag{17}$$

v and ω are the translational and rotational velocity of the end-effector, q is robot positions.

The objectives of Jacobian implementation is to define joint and workspace velocities, the applied forces and torques, and manipulability properties, and understand the singular configurations.

The first step is to define the orientation of rigid body which consists of the Euler angles (ϕ,θ,ψ) associated with z_0, y_1 and z_2. If z axis is at the base frame considered parallel with the end-effector, and the end-effector position is given in eq. 5. The Euler rotation is

$$\begin{bmatrix} \phi\\ \theta\\ \psi \end{bmatrix}=\begin{bmatrix} \theta_1+\theta_2\\ 0\\ 0 \end{bmatrix} \tag{18}$$

The Jacobian of a 2DOFs manipulator shown in fig. 1 is

$$J=\begin{bmatrix} z_0\times\left(p_2-p_0\right) & z_1\times\left(p_2-p_1\right)\\ z_0 & z_1 \end{bmatrix}, \tag{19}$$

where the frame origins are

$$p_0=\begin{bmatrix} 0\\ 0\\ 0 \end{bmatrix},\quad p_1=\begin{bmatrix} a_0c_1\\ a_0s_1\\ 0 \end{bmatrix},\quad p_2=\begin{bmatrix} a_0c_1+a_1c_{12}\\ a_0s_1+a_1s_{12}\\ 0 \end{bmatrix}, \tag{20}$$

and the rotational axes given by

$$z_0=z_1=\begin{bmatrix} 0\\ 0\\ 1 \end{bmatrix}. \tag{21}$$

Therefore, the components of eq. 19 are

$$z_0\times\left(p_2-p_0\right)=-\begin{bmatrix} 0 & 0 & a_0s_1+a_1s_{12}\\ 0 & 0 & -a_0c_1-a_1c_{12}\\ -a_0s_1-a_1s_{12} & a_0c_1+a_1c_{12} & 0 \end{bmatrix}\begin{bmatrix} 0\\ 0\\ 1 \end{bmatrix},$$

$$z_0\times\left(p_2-p_0\right)=\begin{bmatrix} -a_0s_1-a_1s_{12}\\ a_0c_1+a_1c_{12}\\ 0 \end{bmatrix}, \tag{22}$$

$$z_1\times\left(p_2-p_1\right)=-\begin{bmatrix} 0 & 0 & a_1s_{12}\\ 0 & 0 & -a_1c_{12}\\ a_1s_{12} & a_1c_{12} & 0 \end{bmatrix}\begin{bmatrix} 0\\ 0\\ 1 \end{bmatrix},$$

$$z_1\times\left(p_2-p_1\right)=\begin{bmatrix} -a_1s_{12}\\ a_1c_{12}\\ 0 \end{bmatrix}. \tag{23}$$

Hence, the Jacobian matrix is

$$J(q)\dot{q}=\begin{bmatrix} -a_0s_1-a_1s_{12} & -a_1s_{12}\\ a_0c_1+a_1c_{12} & a_1c_{12}\\ 0 & 1\\ 1 & 0\\ 0 & 0\\ 0 & 0 \end{bmatrix} \tag{24}$$

The translational and rotational velocities of end-effector in fig. 1 are

$$\begin{aligned} v&=J_{v1}\dot{q}_1+J_{v2}\dot{q}_2,\\ \omega&=J_{\omega1}\dot{q}_1+J_{\omega2}\dot{q}_2. \end{aligned} \tag{25}$$

where $J_{v1} = -a_0 s_1 - a_1 s_{12}$, $J_{v2} = -a_1 s_{12}$,$J_{\omega 1} = a_0 c_1 + a_1 c_{12}$, and $J_{\omega 2} = a_1 c_{12}$. The column in Jacobian matrix defines the effect of i-th joint on the end-effector velocities.

III. DYNAMICS OF ARM ROBOT MANIPULATOR

Dynamic considers the mathematical equations representing the motion of an arm robot manipulator, which are the motion resulted from the torques applied by the actuators or other external forces applied to the manipulator. The analysis of dynamic starts from a trajectory point or position and calculates the required vector of joint torques. The dynamic analysis also presents the energy needed to move the system.

The generic dynamics of a robot is given by

$$\mathbf{M}(q)\ddot{q} + \mathbf{C}(q,\dot{q})\dot{q} + \mathbf{D}\dot{q} + \mathbf{g}(q) = \tau, \tag{26}$$

$$\mathbf{I}\ddot{\theta} + d\dot{\theta} + mgL\sin\theta = \tau. \tag{27}$$

where $\mathbf{M}(q)$ is a $n \times n$, symmetric and positive definite mass matrix of arm robot manipulator, $\mathbf{C}(q,\dot{q})$ is a $n \times 1$ vector $\mathbf{v}$, a quadratic functions of the joint velocities, $\mathbf{D}\dot{q}$ is the friction, $\mathbf{g}(q)$ is the gravity term, $\mathbf{I}$ is the inertia matrix, and q is robot position.

The derivation of the dynamic is coming from kinematic, and from Jacobian in eq. 24, the Jacobian of each robot's link in fig. 1 are

$$J_v^1 = \begin{bmatrix} -a_1 s_{12} & 0 \\ a_1 c_{12} & 0 \\ 0 & 0 \end{bmatrix}, \quad J_v^2 = \begin{bmatrix} -a_0 s_1 - a_1 s_{12} & -a_1 s_{12} \\ a_0 c_1 + a_1 c_{12} & a_1 c_{12} \\ 0 & 0 \end{bmatrix}, \tag{28}$$

$$J_\omega^1 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \end{bmatrix}, \quad J_\omega^2 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 1 \end{bmatrix}, \tag{29}$$

since the z-axes in the frame of link i and link $i+1$ are parallel to the same axis of $\mathbb{F}_0$, therefore ω is considered the same with ω_z.

Kinetic energy $\mathbf{K}$ of the robot in fig. 1 is

$$\mathbf{K} = \frac{1}{2}\dot{q}^T \left[m_1 {J_v^1}^T J_v^1 + m_2 {J_v^2}^T J_v^2 + {J_\omega^1}^T \tilde{I}_1 J_\omega^1 + {J_\omega^2}^T \tilde{I}_2 J_\omega^2 \right]. \tag{30}$$

where

$${J_\omega^1}^T \tilde{I}_1 J_\omega^1 + {J_\omega^2}^T \tilde{I}_2 J_\omega^2 = \begin{bmatrix} \tilde{I}_1 + \tilde{I}_2 & \tilde{I}_2 \\ \tilde{I}_2 & \tilde{I}_2 \end{bmatrix}. \tag{31}$$

By neglecting friction, the mass matrix $\mathbf{M}(q)$ from eq. 26 is

$$\mathbf{M}(q) = \begin{bmatrix} M_{11} & M_{21} \\ M_{12} & M_{22} \end{bmatrix}, \tag{32}$$

where

$$\begin{aligned} M_{11} &= m_1 a_{c1}^2 + m_2\left(a_0^2 + a_{c2}^2 + 2a_0 a_{c2} c_2\right) + \tilde{I}_1 + \tilde{I}_2, \\ M_{12} &= m_2\left(a_{c2}^2 + a_0 a_{c2} c_2\right) + \tilde{I}_2, \\ M_{21} &= m_2\left(a_{c2}^2 + a_0 a_{c2} c_2\right) + \tilde{I}_2, \\ M_{22} &= m_2 a_{c2} c_2 + \tilde{I}_2. \end{aligned} \tag{33}$$

The quadratic functions of the joint velocities $\mathbf{C}(q,\dot{q})$ from eq. 26 is

$$\mathbf{C}(q,\dot{q}) = \begin{bmatrix} h\dot{\theta}_1 & h\left(\dot{\theta}_1 + \dot{\theta}_2\right) \\ -h\dot{\theta}_1 & 0 \end{bmatrix} \tag{34}$$

where h is calculated from the Christoffel symbols $c_{ijk} = \frac{1}{2}\left[\frac{\partial M_{kj}}{\partial q_i} + \frac{\partial M_{ki}}{\partial q_j} - \frac{\partial M_{ij}}{\partial q_k}\right]$ as follow

$$\begin{aligned} c_{111} &= \frac{1}{2}\frac{\partial M_{11}}{\partial q_1} = 0, \\ c_{121} = c_{211} &= \frac{1}{2}\frac{\partial M_{11}}{\partial q_2} = -m_2 a_0 a_{c2} s_2 = h, \\ c_{221} &= \frac{\partial M_{12}}{\partial q_2} - \frac{1}{2}\frac{\partial M_{22}}{\partial q_1} = h, \\ c_{112} &= \frac{\partial M_{21}}{\partial q_1} - \frac{1}{2}\frac{\partial M_{11}}{\partial q_2} = -h, \\ c_{122} = c_{212} &= \frac{\partial M_{22}}{\partial q_1} = 0, \\ c_{222} &= \frac{\partial M_{22}}{\partial q_2} = 0. \end{aligned} \tag{35}$$

The gravitational forces working on the robot in fig. 1 is given by

$$\begin{aligned} \mathbf{N}(q) &= \dot{\mathbf{M}}(q) - 2\mathbf{N}(q,\dot{q}) \\ &= \begin{bmatrix} 2h\dot{\theta}_1 & h\dot{\theta}_2 \\ -\dot{\theta}_2 & 0 \end{bmatrix} - 2\begin{bmatrix} h\dot{\theta}_1 & h\left(\dot{\theta}_1 + \dot{\theta}_2\right) \\ -h\dot{\theta}_1 & 0 \end{bmatrix} \\ &= \begin{bmatrix} 0 & -2h\dot{\theta}_1 + h\dot{\theta}_2 \\ 2h\dot{\theta}_1 + h\dot{\theta}_2 & 0 \end{bmatrix}, \end{aligned} \tag{36}$$

which is a skew-symmetric.

Therefore, robot dynamic in eq. 26 can be written as

$$\begin{aligned} &M_{11}\ddot{\theta}_1 + M_{12}\ddot{\theta}_2 + c_{121}\dot{\theta}_1\dot{\theta}_2 + c_{211}\dot{\theta}_2\dot{\theta}_1 + c_{221}\dot{\theta}_2^2 + g_1 = \tau_1, \\ &M_{21}\ddot{\theta}_1 + M_{22}\ddot{\theta}_2 + c_{111}\dot{\theta}_1^2 + g_2 = \tau_2. \end{aligned} \tag{37}$$

The potential energy of each links in fig. 1, P_i, are

$$P_1 = m_1 g a_{c1} s_1,$$

and

$$P_2 = m_2 g\left(a_0 s_1 + a_{c2} s_{12}\right). \tag{38}$$

Therefore, the potential energy $\mathbf{P}$ of the arm manipulator is

$$\mathbf{P} = P_1 + P_2 = \left(m_1 a_{c1} + m_2 a_0\right) g s_1 + m_2 g a_{c2} c_{12}, \tag{39}$$

where

$$\begin{aligned} g_1 &= \frac{\partial \mathbf{P}}{\partial \theta_1} = \left(m_1 a_{c1} + m_2 a_0\right) g c_1 + m_2 g a_{c2} s_{12}, \\ g_2 &= \frac{\partial \mathbf{P}}{\partial \theta_2} = m_2 g a_{c2} s_{12}. \end{aligned} \tag{40}$$

Energy kinetic for each links, K_i are given by

$$\begin{aligned} K_1 &= \frac{1}{2} m_1 a_{c1}^2 {\dot{\theta}_1}^2 + \frac{1}{2}\tilde{I}_1 {\dot{\theta}_1}^2 \\ K_2 &= \frac{1}{2} m_2 \dot{\mathbf{p}}_{c2}^T \dot{\mathbf{p}}_{c2} + \frac{1}{2}\left(\tilde{I}_1 + \tilde{I}_2\right)^2 \end{aligned} \tag{41}$$

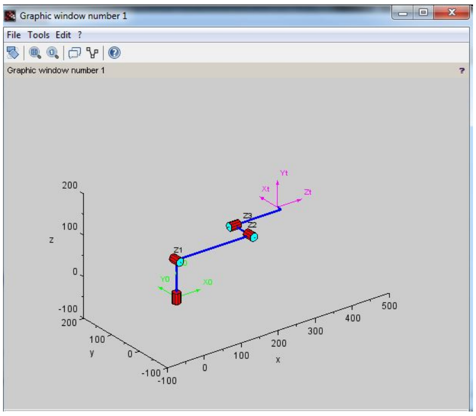

Fig. 2: 4 DOF arm robot simulation in SCILAB

where

$$\dot{\mathbf{p}}_{c2}^T\dot{\mathbf{p}}_{c2} = a_0^2\dot{\theta}_1{}^2 + a_{c1}^2\left(\dot{\theta}_1+\dot{\theta}_2\right) + 2a_0a_{c2}c_2\left(\dot{\theta}_1{}^2+\dot{\theta}_1\dot{\theta}_2\right) \quad (42)$$

IV. SIMULATION AN ARM-ROBOT MANIPULATOR

The arm robot design can be tested in simulation software to ensure the robot follows the reference trajectory. One of open source simulation is SCILAB which is enough to observe robot motion. Fig. 2 shows a 4 DOF arm robot simulated in SCILAB [34].

V. DISCUSSION

In designing arm-robot manipulator, there are 2 steps of modeling, the kinematics and dynamics modeling. This section discusses the application of kinematics, and dynamics modeling and the addition of artificial intelligence to create a more effective system.

A. Kinematics Modeling

Kinematics modeling is required for designing the motion and trajectory of the robot without considering the dynamics aspect such as force and friction. Kinematics modeling can be tested using simulation to avoid the complexity of the real system in testing the effectiveness of the proposed method. Simulation was conducted by Ceccarelli et al. 2008 utilizing the kinematic design for a manipulator by creating an algorithm for evaluating manipulator workspace [4], Lin et al. 2014 proposed an intuitive kinematic control of a robot via interface with human motion to control a robot directly teleoperated in avoiding obstacle and finishing its task [5], Reihara 2011 analyzed and solved the kinematics problem for an AdeptThree robot arm with the application of DH convention simulated in LabView [6], and Zodey et al. 2014 analyze the kinematics of a robotics gripper by simulating the capability of hand modeling, grasp definition, grasp modeling, grasp analysis and graphic to support the presentation [10].

Donelan 2011 investigated the kinematics singularities of a robot manipulator using Kinematics mapping [7]. Song et al. 2011 presented the cyclic coordinate descent (CCD) for computing inverse kinematics in a multi-joint chain robot [8]. Balkan et al. 2006 classified industrial robots based on the kinematic and inverse kinematics structure in order to obtain the simplified forward kinematics equations that will lead to simpler inverse kinematics equation [9]. Kucuk et al. 2006 presented kinematics analysis of a Stanford manipulator [11]. Sultan 2006 also presented the analysis of an arm robot manipulator to design an efficient joint trajectory [12]. A complete analysis and design of an arm robot manipulator mounted on a mobile platform is presented by Clothier et al. 2010 by presenting a geometric method in solving the unknown joint angles to control the autonomous positioning of an arm robot, and the type of end-effector used was a gripper [13].

B. Dynamics Modeling

Dynamics modeling is necessary to create more effective and efficient arm-robot. Muhammed et al. 2014 proposed a method to minimize energy consumption for an arm robot manipulator by solving robot's inverse dynamic to analyze the forces and torques of each joint and link [14]. Dehghani et al. 2014 proposed a dynamic modeling of a continuum robotic arm that has high adaptation and compatibility with the shape of an object to grasp objects [15].

Cen et al. 2017 discussed the effect of dynamics on forces and torques of an arm robot applied in milling industry by designing a force model. The experimental results showed that the proposed method reduced 50% to 70% error for key characteristic of the robot milling's forces [16]. Bruno et al. 2017 proposed the dynamic model identification of an industrial robot that is linear with respect to the parameters [17]. Paik et al. 2012 designed a humanoid robot by taking the model of a 7DOF arm robot and an 8DOF hand. The proposed model was compatible with the narrating model humanoid, and at the same time powerful and functional to execute various task [18].

C. Advance Control

To improve the effectiveness and increase the efficiency, arm robot manipulator trajectory tracking design and control requires more than kinematic and dynamic. The application of advanced control theorem and artificial intelligence are necessary such as adaptive control [19] [20]. Artificial controlled applied in trajectory tracking of an arm robot manipulators are Fuzzy logic controller (FLC) [21] [22] [23], Neural Network (NN) [24] [25] [26], combination of FLC and NN [27] [28] [29] and Genetic Algorithm (GA) [30] [31]. The cumbersome and complication of kinematics and dynamics modeling can be avoided by applying rules-based, and/or learning-based of artificial intelligence.

VI. CONCLUSION

Modeling arm robot manipulator is a complicated work, starting from how it moves in kinematics, and how much energy needed in dynamics. This complicated and exhausting work can be avoided by applying artificial intelligence (AI), namely FLC, NN, and GA. By applying AI, the researcher only needs to considered to map the input-output of the system. However, most of the time, this is not enough, the combination of two types of AI gives a better performance such as ANFIS, and combined the model with forward and inverse kinematics. Arm robot manipulator control and solution is complicated, however, its application is crucial in industries, not to mention, the automatic industry, industry 4.0 is here to create more efficient manufacturing product.

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