A New Concept of Manipulator Modeling

Ho-Sik Roh*, Jin-Oh Kim**

* Department of Information and Control Eng. Kwangwoon University, Seoul, Korea
(Tel : +82-2-940-5158; E-mail: rohhosik@empal.com)
** Department of Information and Control Eng. Kwangwoon University, Seoul, Korea
(Tel : +82-2-940-5158; E-mail: jokim@daisy.kwangwoon.ac.kr)

Abstract: We propose a new method of robot manipulator modeling. Different from existing modelers, our modeler provides a convenient robot modeling configured from modules from module library or module modeling. In addition, a way of using D-H parameters to configure a robot is proposed. These additional functions of robot modeling can be a powerful and flexible tool for various needs of robot modeling. We show an example of modeling with our approach.

Keywords: Robot modeler, Module modeler, D-H parameters, Robot manipulator

1. INTRODUCTION

Existing robot modelers are based on solid-modeling of robots modules that are connect by kinematic relationship. A model can be chosen from existing library by robot language [1] or can be configured from CAD data as in Fig.1 [2]. The robot model library includes a limited number of commercial robot models. However, for a new robot, the existing modelers based on CAD data are very time-consuming and needs long experience. This is mainly because they are made for an entire robot. To overcome these problems, we propose a new easy-to-use and low-cost robot modeler that can create a model easily for a user-own application.

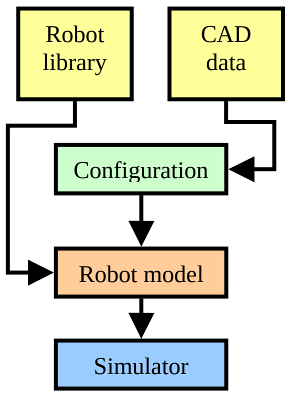


Fig. 1 Robot modeling of existent modelers.

Our modeler, as shown in Fig. 2, has additional functions. In addition to library and CAD data, robots can be modeled from joint and link modules [3]. There are two ways to configure robots.

The first is based on existing module library. Appropriate modules from library is chosen and adjusted by parameters. Then a complete set of modules for a robot are connected and configured to become a robot model. When no module from library is appropriate, we need to create a new module using our module modeler. After a module is created, it is ready to be configured into a robot. For both, D-H parameters are derived after robot configuration.

The second approach is to start with D-H parameters. Once D-H parameters are decided, the kinematic skeleton is made, but they are not enough to form a robot. So we need following steps of designing joint and link modules. Appropriate joint modules are selected from module library and adjusted parametrically. Two adjacent joint modules are connected by an appropriate link module. This way, we continue to form a complete robot interactively.

With these two approaches, we can design a robot for both ways of bottom-up (building blocks; from modules to a robot) and top-down (from robot configuration to modules). In this way, our modeler provides a powerful and flexible tool to cover most of robot modeling, and an easy-to-use/low-cost solution for robot simulation.

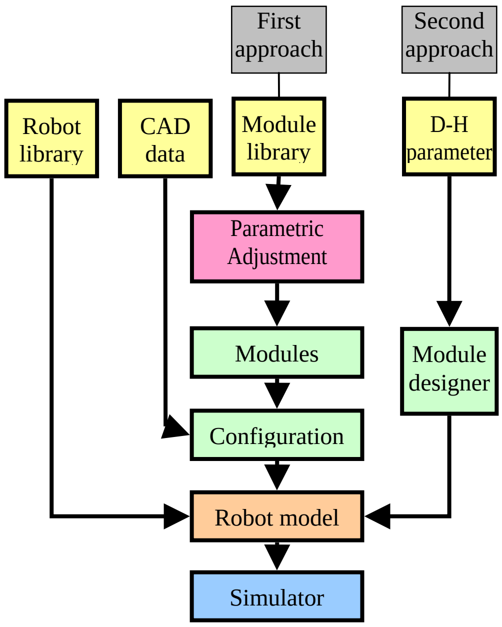


Fig. 2 Propose the robot modeling.

In the following Chapter 2, our module modeling approaches (first and second approached) are explained. In Chapter 4, how to configure a robot from created modules are explained. In Chapter 5, the second approach (Top-down) is explained with an example of modeling of existing robot arm. This includes the entire process from D-H parameters to a robot model. Finally, conclusion is made in Chapter 6.

2. HOW TO USE THE MODELER

Case1: When a robot is modeled from modules (First approach in Fig. 2).

If there is an existing robot with no CAD data, we can use this first approaches. A robot can be modeled module by module. An appropriate set of Joint and Link modules from Module library can be selected and each module can be adjusted parametrically. On the other hand, if there is not appropriate module in the library, we can model a new module using Module modeling. In this approaches, a robot is configured with a set of joint and link modules as we build blocks, from base to end-effector.

This approach can be an educational tool for students. Students can learn inner structure of modules, robot's configuration and the motion.

Case 2: When a robot is modeled from D-H Parameters (Second approach in Fig. 2).

When a proper kinematic configuration (D-H parameters) for the given task is predefined as in [4], this approach becomes very useful. With a set of D-H parameters, we can make a skeleton structure only. We can design each joint and link by our Module designer. We continue to design one by one until we get a final robot model. The detail of this case is explained with an example in Chapter 5.

3. MODULE MODELING

3.1 Module Composition

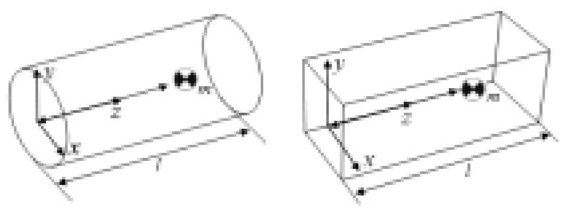
Modules can be divided into Joint modules and Link modules. Joint modules are composed of motors, transmission mechanism and frames. They also have mass and inertia relative to rotation axis. Link modules are just structures with physical dimension (frame of rigid body) but without motion.

For both cases in Chapter 2, the result of robot modeling will be used for simulation. Two kinds of simulations exist; one is kinematic, the other is dynamic. For kinematic simulation, if the input is a set of joints angles/positions and angular/linear velocities, the forward kinematics will create motion of the end-effector. If the input is the position/orientation and the corresponding velocities of the end-effector, the inverse kinematics will generate the motion of all joints. For dynamic simulation, if the input can be torque of all joints, then a dynamic motion can be generated. In this paper, the simulation is out of scope. But we consider both simulations as the following step of robot modeling. Therefore, joint modules needs both of kinematic and of dynamic parameters.

3.2 Link Module

A link module is a solid mechanical object which connects two joints module. The main purpose of a link is to maintain a fixed relationship between the joints module at its ends.

As shown in Fig. 3, a Link module has a base coordinate frame. The base coordinate frame plays the role of the standard in being combined with other modules or in setting kinematic and dynamic parameters.



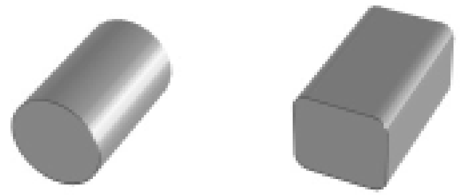


Fig. 3 Link module's coordinate frame.

The kinematic and dynamic parameters of a Link module set through the base coordinate frame were defined as in Table 1.

Table 1 Link module's kinematic and dynamic parameters

Kinematic parameters	- Physical dimension - Length - Width - Diameter
Dynamic parameters	- Center of mass - Moment of Inertia

3.3 Joint Module

Three types of joints are commonly found in robots: revolute joints, rotary joints and prismatic joints. Unlike the joints in the human arm, the joints in a robot are normally restricted to one degree of freedom because of the structural limitation. Revolute or rotary joints provide one degree of rotation, and prismatic or sliding joints provide one degree of translation. Therefore, one joint module can be modeled as two link modules with connection constraint.

The connection constraint between two link modules characterizes a joint module. This constraint consists of the parameters in Table 2.

Table 2 Joint module's Connection Constraints

Revolute or Rotary Joints	- Joint angle limit - Torque (max and nominal) - Angular velocity (max and nominal)
Prismatic Joints	- Stroke limit - Force (max and nominal) - Linear velocity (max and nominal)

Rotational joint modules are used to join links in two basic configurations: collinear (revolute) and orthogonal (rotary). In Fig. 4, a revolute joint has the axis of the rotation parallel with the centre line of the base link. In Fig. 5, a rotary joint has an orthogonal relationship between the axis of rotation and the centerline of the base link. For both, the only variable is a joint angle θ.

A prismatic joint module (Fig. 6) is a sliding joint, with the axis of the joint coincident with the centre line of the base link. A prismatic joint provides one degree of translation, the joint variable is the distance d, and the joint axis is in the z direction.

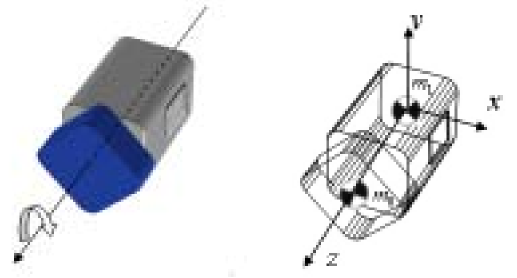


Fig. 4 Revolute joint module with axis coincident with link.

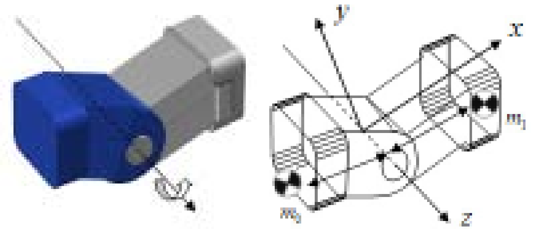


Fig. 5 Rotary joint module with joint axis perpendicular to link.

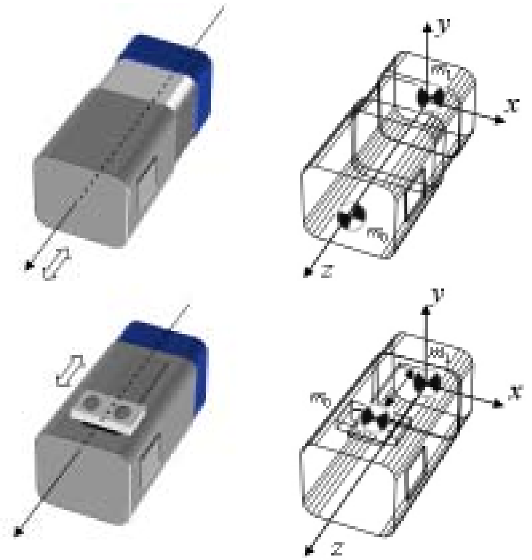


Fig. 6 Prismatic joint module.

3.4 Parametric adjustment

Each joint module has it own kinematic and dynamic characteristics. But the parameters explained in the Section 3.3 can be adjusted to form a real joint module. We can select a set of joint and link modules form the library. It an appropriate type of module does not exist in the library, we can design a new type of joint and link modules by our graphic modeler. In this way, a set of joint and link modules can easily adjusted to be a part of robot of current concern. The change of parameters of a module is made as in Fig. 7.

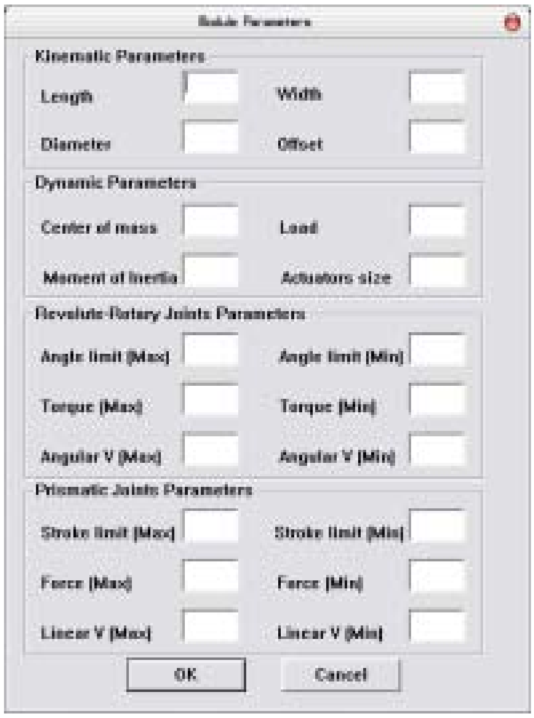


Fig. 7 Module parameter input window.

4. ROBOT CONFIGURATION

After a set of joint and link modules are selected with parameter adjustment, we continue to configure a robot like a building-block. This approach corresponds to the case 1 in Chapter 2. The procedure is composed as follows.

Step 1: Base link is selected as in Fig 8 and the coordinate system is selected as in Fig. 9.
Step 2: 1st joint module are dragged and placed on the base module.
Step 3: 1st link module between 1st joint and 2nd joint.
Step 4: Iterate Step 2 and 3 through the last joint.

Fig. 8 Base link window.

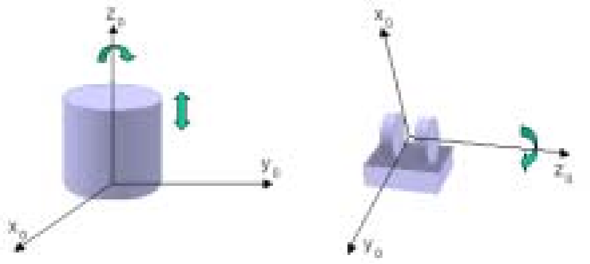


Fig. 9 Base coordinate frame decision.

Now we have a geometrical model of a robot as in Fig. 10 for a six DOF manipulator. We continue to build the physical model. Different from the geometrical model of joint and link modules, physical model consists of links where two adjacent links are connected by a joint. For example, 6 DOF manipulator, the total links are a base frame and six links. Each link has a set of kinematic and dynamic parameters. With this physical model, we select six local coordinate frame in addition to the base coordinate frame. For each coordinate frame, the z axis corresponds to the rotation axis for revolute and rotary joints, and the translation direction for prismatic joints. Once the total local coordinate frames are selected interactively, the corresponding D-H parameters are derived automatically. In this way, we can build a robot model.

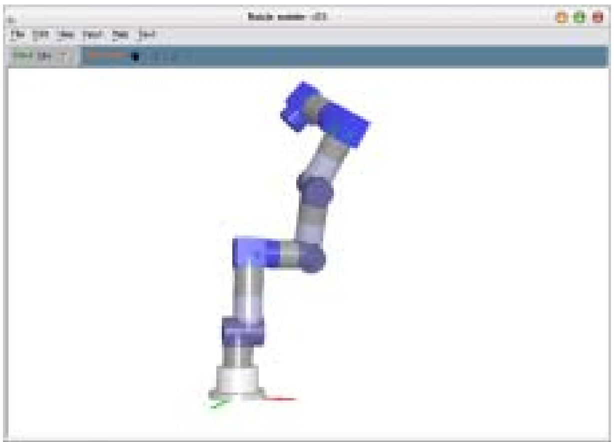


Fig. 10 Geometrical model of a 6 DOF manipulator.

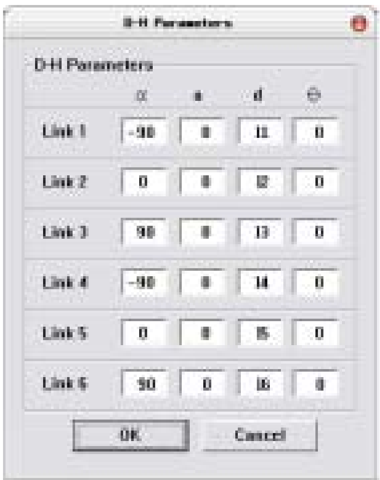


Fig. 11 D-H Parameters from modeling.

5. ROBOT MODELING FROM D-H PARAMETERS

Different from the approach in Section 4, we can build a robot starting from D-H parameters. This approach is very important for MMS in Fig. 12, where joint/link modules exist to configure a manipulator. The optimal kinematic design based on a given task creates an optimal set of D-H parameters.

For a set of D-H parameters, there exist an infinite number of physical models. So we need to develop a procedure to build interactively. But we need to consider existing set of joint modules of MMS. Link modules can easily manufactured and added into MMS. In this case, the manipulator is derived as we find the best-match between the designed D-H parameters and MMS. That is, we have to use only modules existing in MMS and the corresponding module library.

Fig. 12 A Robot configured from MMS (Modular Manipulator System)

Table 3 shows an example of robot kinematic configuration (D-H Parameter set). This set of D-H parameters are used to build a set local coordinate frame and the corresponding skeleton as in Fig. 13. Our Module designer helps to form a manipulator from this skeleton. First, we select candidates of joint modules for each joint. Different dynamics of joint modules need to be considered when a joint module is selected from the candidates. After selection of joint modules, we select link modules connecting two adjacent joint modules. Different from joint modules, we are free to select to adjust parameters of link modules. The whole interactive process is in our Module designer routine. In this way, we can get to the complete physical model corresponding to Table 3 as in Fig. 15.

Table 3 D-H parameter set

Link number	θ	a	d	α
1	θ_1	0	l_1	$-90°$
2	θ_2	0	l_2	$+90°$
3	θ_3	0	l_3	$+90°$
4	θ_4	0	l_4	0
5	θ_5	0	0	$-90°$
6	θ_6	0	0	0

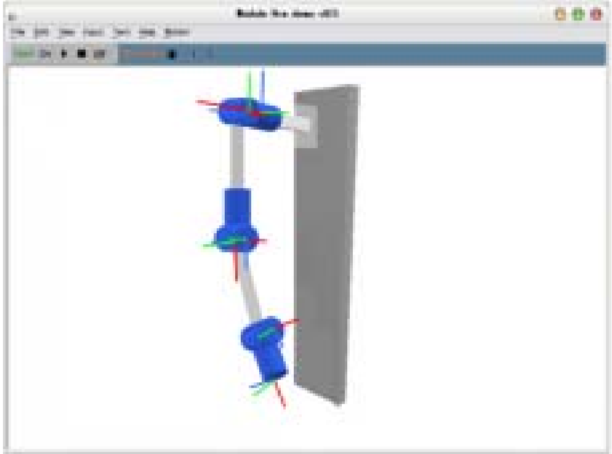


Fig. 13 Kinematic skeleton

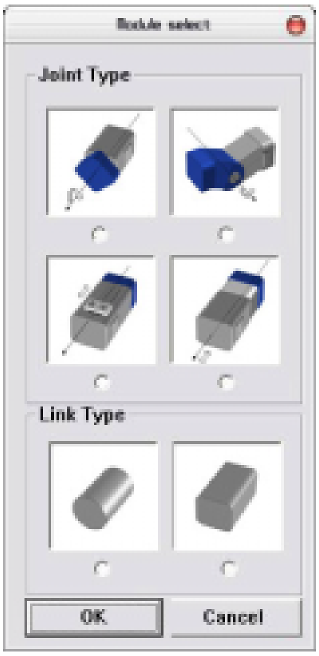


Fig. 14 Module selection.

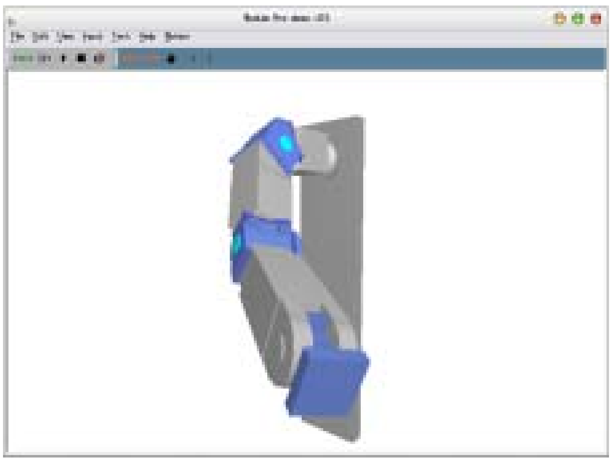


Fig. 15 Final Robot Modeling.

6. Conclusion

In this paper, we propose two new approaches of robot modeling. One is based on library of joint and link modules, while the other is based on D-H parameters. The first is good to build a robot like building-blocks. The interactive way of modeling makes the whole process easy and flexible. The second is good for MMS where D-H parameters can be derived from kinematic design based on a given task. We believe both approaches provide a powerful tool of modeling for educational and industrial use.

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