Standing Control of a Four-Link Robot

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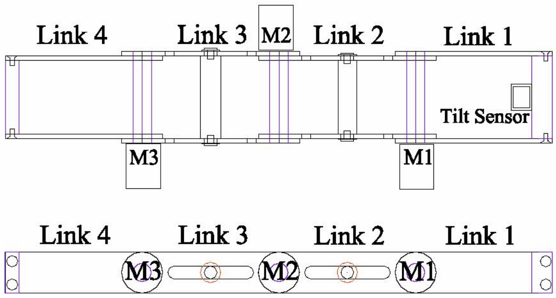
Abstract *- The objective of this paper is to design a neural-fuzzy controller for a four-link robot to stand up vertically and stably from a flat horizontal surface. There are a structural mechanism, a PC, a tilt sensor and three stepping motors in this robot system. The sequence of standing behavior of this robot is designed and assigned by a developed software program in a PC. The artificial neural network (ANN) and fuzzy control algorithm are applied to develop the standing controller for this robot. The position of the center of gravity (COG) is an important factor to determine the stability of the robot. Finally, the robot links are driven by the corresponding motors to demonstrate its dynamic behaviors successfully and automatically.*

keyword：Four-link robot, Fuzzy control, ANN, COG

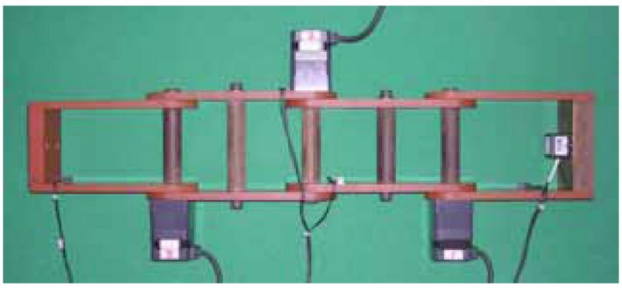
1. Introduction

The field of robotics research is very extensive recently. There are many functional robotics all over the world [1-5]. Prof. Doya investigated a three-link robot to stand up automatically from a flat horizontal surface [6]. Liao and Tsai studied the standing and crawling control of a developed three-link robot control by the fuzzy theory [7-8]. Their mechanisms of the three-link robots [6-8] are simple and easy to manipulate. It will be more complicated to control a four-link robot to stand up smoothly than a three-link robot.

The objective of this paper is to design a fuzzy controller for the four-link robot to stand up from a flat horizontal surface successfully and smoothly (Fig. 1). There are three joints and four links which are equal in length in this robot system. The joints are controlled by three stepping motors respectively. In the standing processes, a tilt sensor is used to detect the real-time horizontal angle of the robot bottom surface.



(a)



(b)

Figure 1. (a) Top view and side view of the robot structure
(b) Picture of the four-link robot

2. Standing behavior plan

From the dynamic stability point of view, it is necessary to calculate the individual center of gravity (COG) of these four links in order to find out the real COG of this robot system. For example, the center of gravity of link 1 (G_1) is calculated by the length and the weights of the link and the motor (Fig. 2).

$$\ell_{G1} = \frac{M_1 * \ell_1 + M_{L1} * \ell_1/2}{m_0 + M_{L1} + M_1} \qquad (1)$$

where

l_1: the length of link 1.

M_{L1}: the weight of link 1.

M_1: the weight of motor M1.

m_0: the weight of bottom part of this robot.

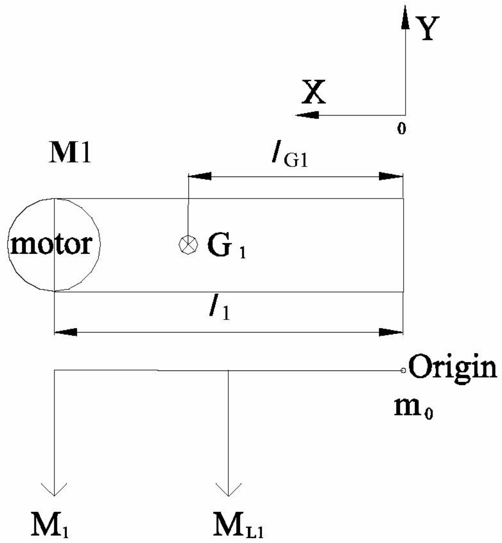


Figure 2. The center of gravity of link 1

Then, the real COG of the robot system is calculated by the similar method (Eqn. (2)-(3)). G_i is the COG of link i (Fig. 3). M_{Li} is the total weight of link i. G_{all} is the real COG of this robot system. l_i is the length of link i. α is the angle of link 1 to be rotated by motor M1. β_1 is the angle of link 2 to be rotated by motor M1 and M2. Similarly, β_2 is the angle of link 3 to be rotated by motor M2 and M3. β_3 is the angle of link 4 to be rotated by motor M3. The above angles will be positive if it is rotated clockwise and negative if it is rotated anti-clockwise.

$$G_{all} = \frac{\sum_{i=1}^{4} G_i * M_{Li}}{\sum_{i=1}^{4} M_{Li}} \qquad (2)$$

$$COG_{all} = \frac{COG_1 M_{L1} + COG_2 M_{L2} + COG_3 M_{L3} + COG_4 M_{L4}}{M_{L1} + M_{L2} + M_{L3} + M_{L4}} \qquad (3)$$

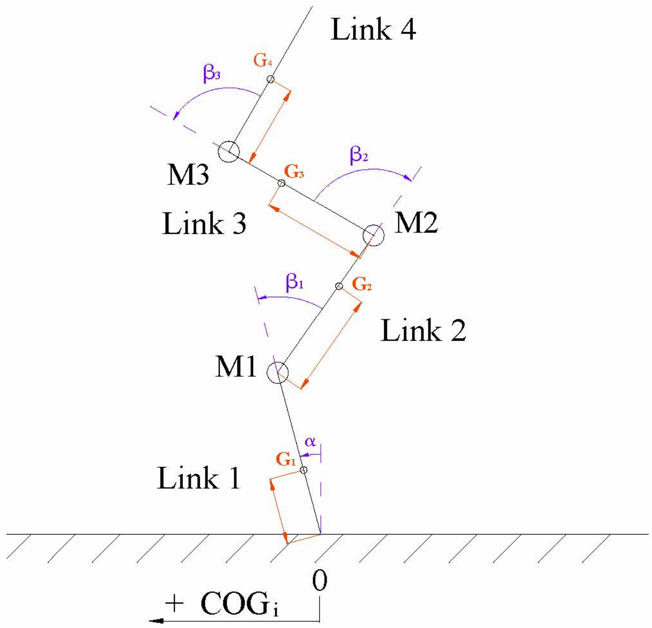


Figure 3. The COG of link1 to link 4

The sequence of standing behavior is designed and assigned as following (Fig. 4).

Step (1): the robot lies down on a flat horizontal surface.

Step (2): let link 2 and link 3 lean the joint 2 upward.

Step (3): let link 1 and link 4 stand up in parallel vertically.

Step (4): let link 1 lean a small angle (θ_{L1}) which is determined by the developed ANN software program in order to change the real COG of the robot system before standing up (Fig. 5).

Step (5): let link 4 rotate clockwise suddenly to make link 1 stand up stably.

Step (6): rotate link 4 upward to make the robot stand up vertically by controlling motor 1 (M1) only.

Step (7): the link 2 is driven by motor 1 (M1) to change its real COG in order to stand up vertically smoothly by the developed fuzzy controller.

Step (8): the final status of this standing robot.

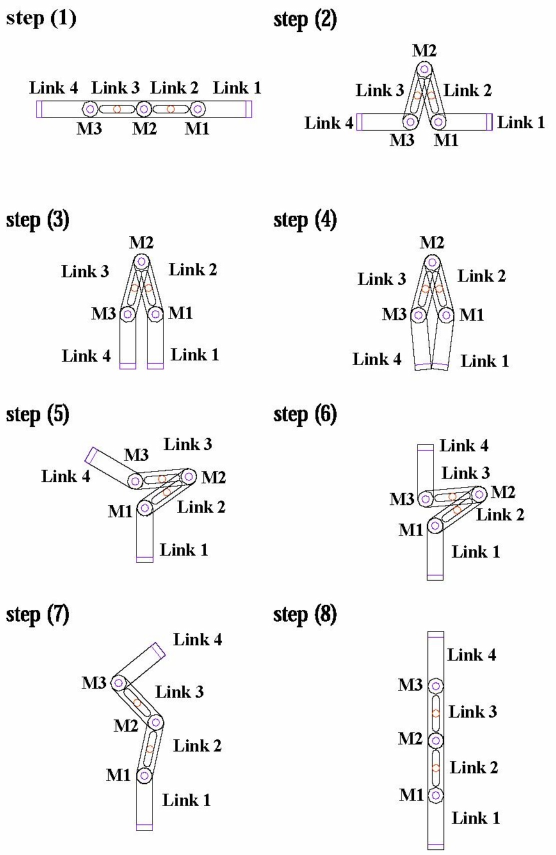


Figure 4. Standing sequence of the four-link robot.

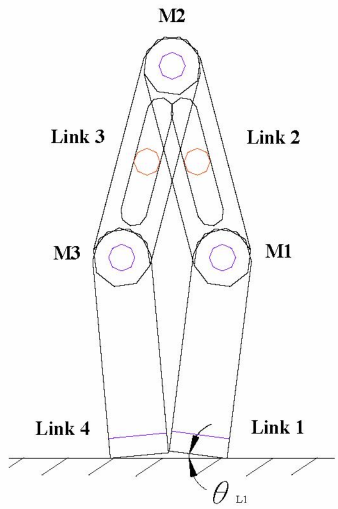


Figure 5. Inclined angle of the Link 1 (θ_{L1})

3. Control theory

In the research, the ANN theory is applied to develop a predictive model of the inclined angle (θ_{L1}), and the rotating angular velocity (ω_{M1}, ω_{M3}) of M1 and M3 for the standing processes (step (4)-(5), Fig. 4). The fuzzy theory is applied to develop the standing controller for the motor 1 (M1) (step (6)-(8), Fig. 4).

3.1 Artificial Neural Network (ANN)

There are three layers in the back propagation network (BPN) structure of ANN (Fig. 6). The input variables are the inclined angle (θ_{L1}) of link 1 with respect to the horizontal surface (Fig. 5), and the angular velocity (ω_{M1}, ω_{M3}) of the motor M1 and M3. The output variable Y is 1 (standing up successfully) or 0 (standing up unsuccessfully).

The results of this ANN model are sent to the robot system to make link 1 lean a small angle (θ_{L1}) before standing up (step (4)), and let link 4 rotate clockwise suddenly to make link 1 stand up stably (step(5)) (Fig. 4).

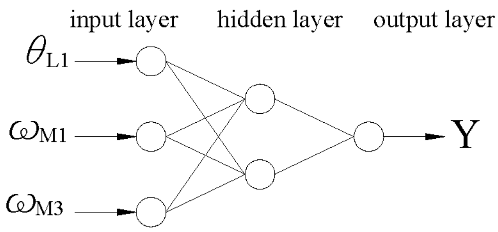


Figure 6. Back propagation network of this robot system

3.2 Fuzzy controller

A fuzzy controller of motor 1 (M1) is designed to make this four-link robot stand up from a horizontal flat surface stably and smoothly. In the standing processes (Fig. 4), the rotating speeds of motor 2 and 3 are assumed to be constant respectively but in the opposite direction. At the same time, the link 2 is driven by the motor 1 (M1) to adjust the real COG of this robot to stand up stably.

The control block diagram is shown in figure 7. The system input variable (r_b) is the desired COG of this system. It is the original point O in this case (Fig. 8). The output variable (X_b) is the measured COG of this system (Fig. 8). The input variables of the fuzzy controller are C_E and ω_b. C_E is the position error between r_b and X_b. ω_b is the angular velocity of motor 1 (M1). The output variable ($\triangle\omega_b$) of the fuzzy controller is the change of ω_b. The corresponding membership function is shown in figure 9. The range [-27.5, 27.5] of C_E is assigned by the bottom width of the robot (Fig. 8). The range [-36, 36] of ω_b and the range [-72, 72] of $\Delta\omega_b$ are determined from the robot system experimentally. Then, the fuzzy rule base (Table. 1) is developed by the membership function (Fig. 9). There are twenty five rules in the fuzzy rule base. Finally, the fuzzy command is executed by the driving motor 1 (M1) based on this rule base.

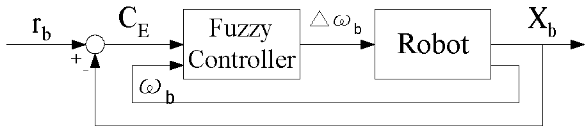


Figure 7. Control block diagram

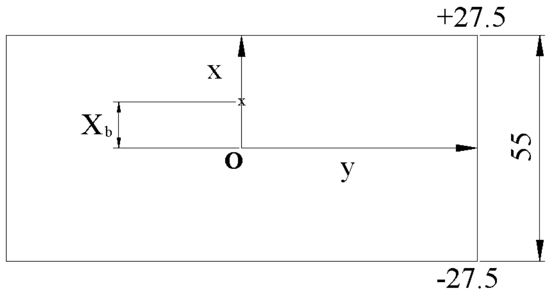


Figure 8. Bottom part of the robot

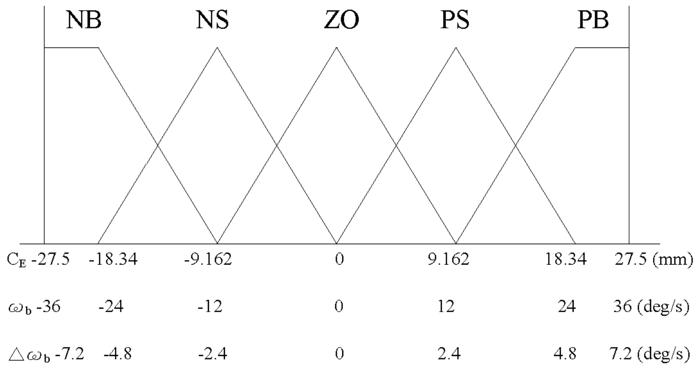


Figure 9. Membership function of the fuzzy controller

Table 1. Fuzzy rule base

		C_E				
	$\triangle\omega_b$	**NB**	**NS**	**ZO**	**PS**	**PB**
ω_b	**NB**	ZO	PS	PB	PB	PB
	NS	NS	ZO	PS	PB	PB
	ZO	NB	NS	ZO	PS	PB
	PS	NB	NB	NS	ZO	PS
	PB	NB	NB	NB	NS	ZO

4. Experimental setup

The robot system is composed of a structural mechanism, a PC, a tilt sensor, and three stepping motors with corresponding driving controllers (Fig. 10). The software Visual Basic (VB) is used to design the control interface in a PC. The tilt sensor will help us to determine the stable status of this robot system in the experiment.

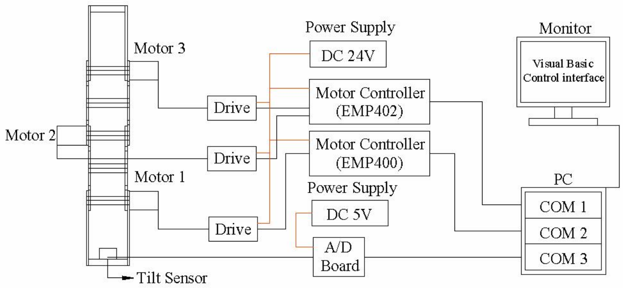


Figure 10. System experimental setup

5. Conclusions and Discussion

Figure 11 shows the experimental results of this four-link robot in eight pictures taken by a digital camera continuously. The developed robot is able to stand up successfully and automatically. We hope to develop another intelligent controller to implement its learning ability automatically if the length or the weight of the robot link is changed in the future research.

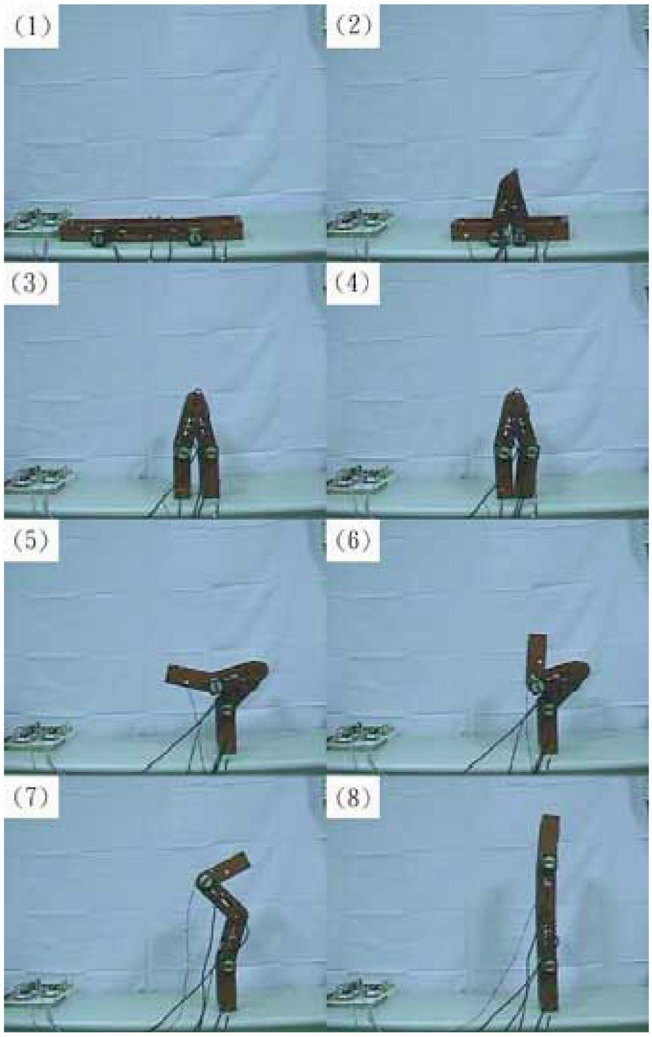


Figure 11. The experimental results

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