Robot Arm Control Simulation by Inverse Kinematics based on Fuzzy Logic

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I. Introduction

Multi-joint small robots are widely used in households and the general public and are becoming increasingly complex and sophisticated. Small robots should be able to perform a wide range of movements and tasks in a limited space, have high processing capacity, and should be economical. In the future, the small robot technology can meet the diverse demands, and expect useful in everyday life. Whereas, multi-joint control of operation and actions have been studied for planning robot paths using dynamics or kinematics. However, for entertainment robots and amusement robots to generalize, and to coexist in daily life, high-speed operation and high precision are not necessarily often requested. The present path planning techniques are not suitable for small, low-cost, and general-purpose microprocessors, because the use of mathematical functions increases the computational burden, and the little memory space in the small microprocessors are consumed. Therefore, the easy and convenient technology must be developed to operate robots under regulated conditions [1-4].

In this paper, we propose an inverse kinematics algorithm to reduce the burden of control microprocessors in multijoint robot model, which is necessary to integrate small autonomous robots into daily life. In addition, by simulation, we analyze the effectiveness of the proposed control method that applied a link mechanism with multiple joints.

II. Fuzzy Control Model for Multi-joint Robot

In this section, we introduce an inverse kinematic control model based on fuzzy logic for the upper body of a multi-joint robot. A limb with n joints can be controlled using the following inverse kinematic control model based on fuzzy logic for the upper body of multi-joint robot. The ith control rule is given by the fuzzy relationship R_i defined by space (x, y, θ), where x and y are the coordinates of the fingertip and θ is the joint angle. Then, the fuzzy relationship of the robot mechanism joints is expressed as

$$R_y = (x,\ y,\ \theta_j) \qquad (1)$$

where j denotes a specific joint, *e.g.*, shoulder, el-

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bow, or wrist joint.

The following four rule bases use the sentence connective “also”:

$$R_{SP} = \bigcup_{i=1}^{n} R_{iSP} \quad \text{or}$$
$$R_{SY} = \bigcup_{i=1}^{n} R_{iSY} \quad \text{or}$$
$$R_{EN} = \bigcup_{i=1}^{n} R_{iEN} \quad \text{or} \tag{2}$$
$$R_{WN} = \bigcup_{i=1}^{n} R_{iWN}$$

Here, SP, SY, EN, and WN denote the shoulder pitch, shoulder yaw, and elbow and wrist joints, respectively.

Input membership function $\mu_{i1}(x)$ of the x coordinate and input membership function $\mu_{i2}(y)$ of the y coordinate are defined as

$$\omega_i = \mu_{i1}(x) \wedge \mu_{i2}(y) \tag{3}$$

where ω_i is the grade of the ith rule. The maximum grade for this system is 255, and using this step, the grade value can be truncated to an integer value using input x. In general, the fuzzy relationship between the input and output membership function $B_{ij}(\theta_j)$ is expressed as

$$B_j^o(\theta_j) = [\omega_1 \wedge B_{1j}(\theta_j)] \vee [\omega_2 \wedge B_{2j}(\theta_j)] \vee \dots \vee [\omega_n \wedge B_{nj}(\theta_j)] = \bigvee_{i=1}^{n} [\omega_i \wedge B_{ij}(\theta_j)] \tag{4}$$

Here, the measurement points are set to x^0 and y^0; an input of (x^0, y^0) yields output joint angle $B_j^0(\theta_j)$. In equation (4), $\wedge$ is the minimum criterion logic, $\vee$ is the maximum criterion logic, and function B^0 overlaps each output membership result, which are reduced to their fuzzy set in equation (3).

We aim to increase the joint control performance using a lightweight algorithm; therefore, we apply the center-of-gravity defuzzification method using a singleton-type output membership function.

$$\theta_j = \frac{\sum_{i=1}^{n} \omega_i B_{ij}}{\sum_{i=1}^{n} \omega_i} \tag{5}$$

This fuzzy logic control model will be applied to multi-jointed robots. Thus, this logic can derive each joint angle from the tip coordinate of the limb. Moreover, because this algorithm is, by definition, an integer variable system, any decimal value obtained by division is rounded down according to the microprocessor specifications.

III. Simulation of Human Motion

To achieve these aims, we analyzed the movements of a moving human arm on a desk, *i.e.*, a 2D plane surface. In this analysis, nine points (corner points, diagonal intersection point, and midpoints of the sides of a rectangle) were selected beforehand. Next, the human subject was asked to continuously move his arm over the plane containing the nine points. These movements were video recorded from three directions (top, front, and side). this movements determined the following from the three sampling images: This simulation results are shown in ***Fig. 1***.

1) Each joint angle (shoulder, elbow, and wrist; from the top image)
2) Straight line angle that connects the hand to the shoulder (from the side image)

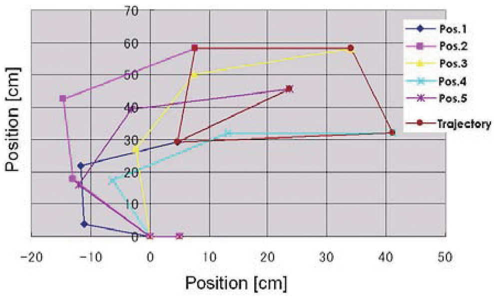

Fig. 1 Simulation of a human arm model.

3) Distance between the desktop and the fingertips (from the front image)

IV. Robot Control Model

This study focused on a 4-DOF robot arm that can move over 2D planes such as tables. In other words, the control system of this robot has 2 inputs and 4 outputs (***Fig. 2***). In this robot system, When the (*x*, *y*) coordinate of an arbitrary position on a 2D plane is inputted to this robot system, a system is required which can calculate four joint angles by using the inverse kinematics algorithm. We attempted to apply the fuzzy controller to a 4-DOF manipulator of a small autonomous robot controller. ***Fig. 3*** shows the block diagram of the control section of this system. The advantage of the fuzzy model is that it can be applied to small microprocessors for developing small robots or for easily modeling the behavior of humans or animals.

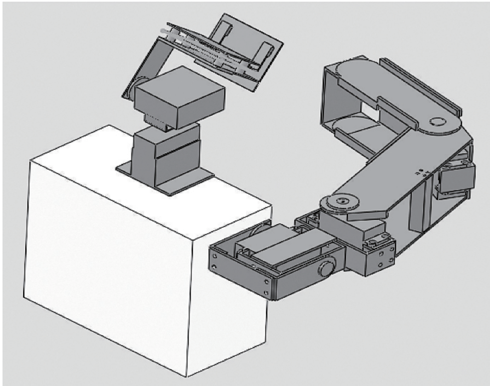

Fig. 2. Upper body robot model.

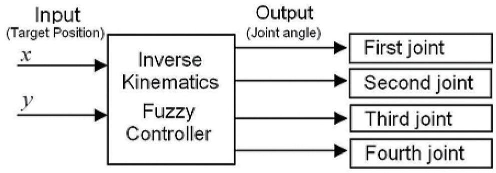

Fig. 3. Block diagram of the Fuzzy Controller.

V. Simulation Analysis and Results

We experimentally investigated the validity of the model by simulation. In the survey method, the inverse kinematics fuzzy control model was implemented in a microprocessor using human motion analysis results, and experiments were conducted using a model using a 4 - DOF robot arm. We investigated the behavior of the robot when it was intermittently operated a plane with horizontal and vertical, such that movement was limited within a rectangle of dimensions 500 [mm] × 250 [mm]. Error distribution of the robot arm tracing at intervals of 20 [mm] are shown in ***Figs. 4*** and ***5***.

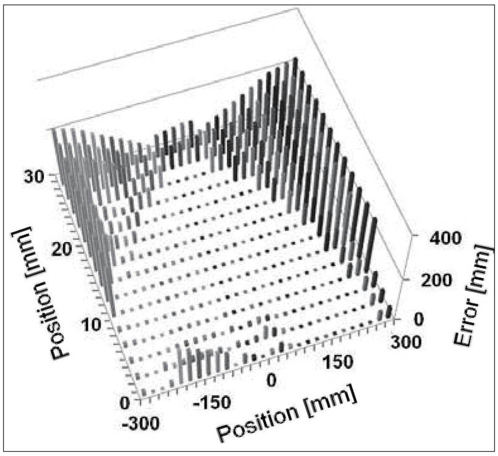

Fig. 4. Simulation results of the alignment errors on the x coordinate of the fingertip.

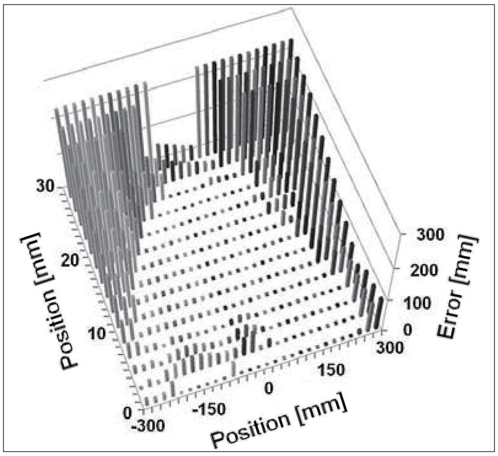

Fig. 5. Simulation results of the alignment errors on the y coordinate of the fingertip.

VI. Conclusion

This paper has outlined an inverse kinematic model consisting of fuzzy logic and proposed a method to realize joint angle integer arithmetic using the fuzzy inverse kinematics. Furthermore, we have confirmed the control error and reproducibility of this model based on the original target behavior when deriving this inverse kinematic model. We have furthermore shown that generating the approximated behavior of the original motion is possible. Moreover, the fuzzy inverse kinematic model is shown to be a simplified calculation method that discretizes the real variables of a conventional robot joint-control program.

Although the model in this study was evaluated through the simulation experiment with the robot performing a planar controlled motion, future work will involve evaluating three-dimensional space controlled objects or motion using the proposed inverse kinematic model that includes the results of our previous research.

[References]

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