INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING Vol. 18, No. 3, pp. 293-299 MARCH 2017 / 293

REGULAR PAPER

DOI: 10.1007/s12541-017-0037-0
ISSN 2234-7593 (Print) / 2005-4602 (Online)

Design Optimization Method for 7 DOF Robot Manipulator Using Performance Indices

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KEYWORDS: Design optimization, Kinematic performance indices, Dynamic performance indices, Energy efficiency

This paper proposes an optimal design method for the design parameters that affect the performance of 7 degrees of freedom (DOF) serial manipulators. The proposed method optimizes the manipulator parameters by using performance indices related to the distribution of inertia, while considering the workspaces and dexterity that correspond to the kinematic performance, and the energy that corresponds to the dynamic performance. The Structural Length Index (SLI) and Global Conditioning Index (GCI), which are kinematic performance indices, and the Modified Dynamic Conditioning Index (MDCI), which is a dynamic performance index, were used as objective functions. After deriving the parameters that affect manipulator performance through these performance indices, a Genetic Algorithm was used for the optimization. This method should be helpful in theoretically designing those parameters that have been created by relying on experience, thus far, in the initial conceptual design stage in 7 DOF manipulator designs.

Manuscript received: June 22, 2016 / Revised: October 5, 2016 / Accepted: October 6, 2016

NOMENCLATURE

SLI = Structural Length Index
GCI = Global Conditioning Index
MDCI = Modified Dynamic Conditioning Index

1. Introduction

Robot manipulators exhibit diverse forms and structures, depending on the work needed. In particular, 6 DOF robot manipulators that can perform several individual jobs are those most frequently used at industrial sites. As the use of robots has spread from the fields of industry to service, robots that can perform diverse work, like humans, are in demand, and of those, robots with higher DOF are in demand. Accordingly, 7 DOF robot manipulators have been studied extensively over the last two decades or more. With regard to those degrees of freedom required to perform work in 3D spaces, 3 DOF each are necessary for the position and direction, respectively, with an additional DOF added in the case of 7 DOF robot manipulators, to enable more diverse motions and functions, such as obstacle avoidance.

In the case of robot manipulators, certain parameters, such as the joint structure and the length/weight of the link, are designed based on the required performance and work. Therefore, an important aspect of robot design is identifying those parameters that affect robot performance.[1,2] To fulfill these parameters, most designers rely on their experience, or the results of the analyses of other similar products. These methods can create the problems of undergoing many trials and errors, as well as requiring large amounts of time and money. To solve these problems, a number of studies have been conducted to determine the design parameters by approaching the determination as an optimization problem, and to evaluate and improve robot performance through simulations.[4-8] Robot models and performance indices are necessary to evaluate robot performance. These robot models include those that use modular synthesis to determine the robot structure, and those that use non-modular synthesis methods to determine robot structure, using only instrumental information [i.e., Denavit-Hartenberg (DH) parameters].[3]

The performance indices can be divided into kinematic and dynamic, with the kinematic performance indices consisting of the manipulability[10] and condition numbers[11] that indicate the dexterity for certain postures (or certain works), the Global Conditioning Index[20]

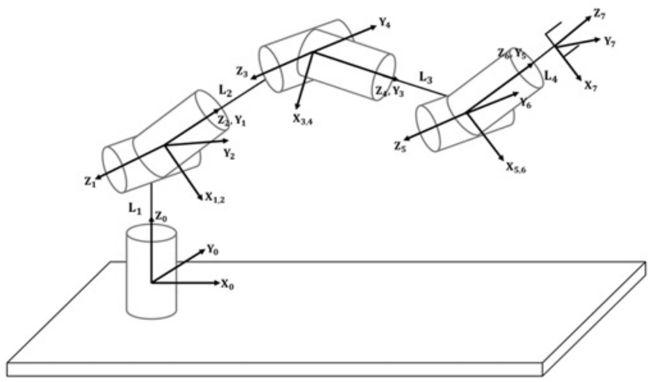

Fig. 1 Configuration of the 7 DOF robot manipulator

that indicates the dexterity for the entire workspace, and the Structural Length Index[6] that indicates the efficiency of workspaces. The dynamic performance indices include Dynamic Manipulability[12] and the Inertia Matching Index,[13] used to measure the performance of end-effectors in terms of acceleration and the force from joint torque, and the Dynamic Conditioning Index[14] that expresses the degree to which robot manipulators' inertia matrices indicate dynamic isotropy. Most of the design optimization studies using performance indices have addressed only the kinematic part, and even those that addressed the dynamic part had problems with the actual application, since the associations between the parameters were not considered.

In this paper, an optimal design method for the parameters that affect the performance of 7 DOF robot manipulators has been proposed. The kinematic performance and dynamic performance of robots were simultaneously considered, and the design parameters were derived considering their associations with each other. The kinematic/dynamic performance indices were used as objective functions, while the Global Conditioning Index (GCI) and the Structural Length Index (SLI) were used to improve the kinematic performances in terms of workspace and dexterity. The Modified Dynamic Conditioning Index (MDCI) was used as a dynamic performance index in the design, so that the robot manipulators' mass-inertia matrices were appropriately distributed for the enhancement of energy efficiency, and since the performance was evaluated through Kinetic Energy. For optimization, a Genetic Algorithm was used so that the method would be sturdy against many parameters, with high non-linearity, and would not fall in local optimum points.

2. Kinematic and Dynamic Analyses

For the optimum kinematic design of 7 DOF robot manipulators, one study[16] proposed (Fig. 1) considering the elimination of singularity, mechanical realizability, kinematic simplicity, and workspace shapes. The 7 DOF robot manipulator applied in this paper has the same structure, and the individual joints and links were assumed to be cylindrical in order to reduce the number of design parameters. In addition, kinematic and dynamic modeling was conducted to derive the objective functions necessary to optimize the design parameters.

Table 1 Denavit-Hartenberg link parameters

Joint No.	Link parameters			
	α_i	a_i	d_i	θ_i
1	$\pi/2$	0	L_1	θ_1
2	$-\pi/2$	0	0	θ_2
3	$\pi/2$	0	L_2	θ_3
4	$-\pi/2$	0	0	θ_4
5	$\pi/2$	0	L_3	θ_5
6	$-\pi/2$	0	0	θ_6
7	$\pi/2$	0	L_4	θ_7

2.1 Kinematics

The DH expression model has been used as a standard for expressing robots and modeling their movements.[9] Cartesian coordinates are attached to the individual links, as shown in Fig. 1, while Table 1 shows the definitions of the DH parameters.

a_i = Distance from Z_{i-1} to Z_i measured along X_i

α_i = Angle between Z_{i-1} and Z_i measured for X_i

d_i = Distance from X_{i-1} to X_i measured along Z_{i-1}

θ_i = Angle between X_{i-1} and X_i measured for Z_{i-1}

Using Fig. 1 and Table 1 above, the position and direction of the end-effector in relation to the fixed reference coordinates can be expressed as follows:

$$T(q) = \begin{bmatrix} \boldsymbol{R}_e(q) & \boldsymbol{p}_e(q) \\ \mathbf{0}^T & 1 \end{bmatrix} \tag{1}$$

where $q = [q_1, q_2, \ldots, q_7]^T$ is a joint variable, and $R_e(q)$ and $p_e(q)$ refer to the orientation matrix and position vector of the end-effector, respectively.

2.2 Differential kinematics

The relationships between the position/direction of the end-effector and the joint variable are expressed as shown in Eq. (1); however, the relationships between the linear and angular velocities of the end-effector and the joint velocity are expressed by differential kinematics. According to one study,[17] the following relationships based on differential kinematics are valid:

$$\begin{bmatrix} v_e \\ \omega_e \end{bmatrix} = J(q)\dot{q} \tag{2}$$

$$J = \begin{bmatrix} J_P \\ J_O \end{bmatrix} \tag{3}$$

In Eq. (3), J_P is a 3×7 matrix that defines the relationship between the joint velocity $\dot{q}$ and the end-effector linear velocity v_e, and J_O is a 3×7 matrix that defines the relationship between the joint velocity $\dot{q}$ and the end-effector angular velocity ω_e. (6×7) matrix J, which is a function of the joint variable q, and is described as Jacobian.

Since the Jacobian matrix enables the identification of kinematic conditions as explained above, many researchers have used to evaluate the performance of robot manipulators.[22] Therefore, the performance indices intended to measure the kinematic conditions of robot manipulators have been used in the optimal design for the determination of the design parameters.

2.3 Dynamics

There are two methods used most frequently to derive the equation for the motion of robot manipulators. The first method is the Euler-Lagrange method (energy-based approach), which is good for the analysis of the dynamic properties and control methods. The second method is the Newton-Euler method (balance of force/torque), which is good for the implementation of the control methods. In this paper, the Euler-Lagrange method was used to analyze the dynamic properties and in the design. The Euler-Lagrange formulation is as follows:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right)-\frac{\partial L}{\partial q_i} = \tau_i \ ; \ i = 1,\ldots,7 \tag{4}$$

where the Lagrangian $L = K - U = \Sigma_{i=1}^{7}(K_i - U_i)$, and the kinetic energy and potential energy of the ith link and joint are as follows:

$$K_i = \frac{1}{2}m_i\mathbf{v}_{ci}^T\mathbf{v}_{ci} + \frac{1}{2}\omega_i^T\mathbf{I}_i\omega_i, \ \ U_i = m_i\mathbf{g}^T\mathbf{p}_{ci} \tag{5}$$

where $\mathbf{v}_{ci}$ is the linear velocity of the center of mass of link I, and ω_i is the angular velocity of link i. $\mathbf{I}_i$ is the mass-inertia matrix for the center of mass of link I, and $\mathbf{p}_{ci}$ is the position vector of the center of mass of link i measured at the reference coordinates.

Eq. (5) can be substituted into Eq. (4) to derive the following equation of motion:

$$M(q)\ddot{q} + C(q,\dot{q}) + G(q) = \tau \tag{6}$$

where M is the mass-inertia matrix, C is the vector of Coriolis and centrifugal, G is the vector of gravitational forces, and τ is the vector of the joint torques.

2.4 Trajectory generation

The joint trajectory should be generated to analyze the torque that acts on the joints of the robot manipulator, and the 5th order polynomial was applied for the simulation of the desired task. If the initial position and final position of the joint and working hours are known, the position, velocity, and acceleration profile of the joint can be obtained as follows:

$$q(0) = q_i \quad q(t_f) = q_f$$

$$\dot{q}(0) = \dot{q}_i \quad \dot{q}(t_f) = \dot{q}_f$$

$$\ddot{q}(0) = \ddot{q}_i \quad \ddot{q}(t_f) = \ddot{q}_f$$

Based on the above boundary conditions, the position, velocity, and acceleration can be calculated as follows:

$$q(t) = s_0 + s_1 t + s_2 t^2 + s_3 t^3 + s_4 t^4 + s_5 t^5$$

$$\dot{q}(t) = s_1 + 2s_2 t + 3t_3 t^2 + 4s_4 t^3 + 5s_5 t^4$$

$$\ddot{q}(t) = 2s_2 + 6s_3 t + 12s_4 t^2 + 20s_5 t^3$$

where, subscripts i and f refer to the initial and final, respectively.

3. Performance Indices

Since 7 DOF manipulators should be able to perform diverse work swiftly, the major kinematic performances include the workspace and dexterity. The workspace is determined by the link length and joint range of the manipulator, and can be evaluated by calculating the volume. Dexterity refers to handling objects precisely, with fluency, and can be measured using the Jacobian matrix.

When designing a robot manipulator, weight lightening is an important factor, because when the weight is lighter, the robot manipulator can move faster, with less energy. In other words, the same work can be performed using a smaller motor. Since the robot manipulator addressed in this paper performs rotary motion, it should be designed to be light-weight, with a small inertial moment. These dynamic properties can be analyzed through the mass-inertia matrixes obtained from the kinetic models.

The SLI and the GCI were used as performance indices to measure the kinematic properties,[19] and the MDCI was used as a performance index to measure the dynamic properties. These performance indices were used as objective functions for the optimal designs.

3.1 Structural Length Index (SLI)

For a robot manipulator to perform diverse work, its reachable workspace volume should be maximal. In general, robot manipulators with longer link lengths and wider joint ranges have larger reachable workspace volumes; therefore, two different robot manipulators having the same link length and different joint ranges may have the other reachable workspaces. The structural length index is a global performance index for measuring reliable reachable workspaces. It is the ratio of the link length sum to the cube root of the reachable workspace volume of the robot manipulator, and is defined as follows:

$$Q_L = \frac{L}{\sqrt[3]{V}} \tag{7}$$

where V is the volume of the reachable workspace, and L is the link length sum.

$$L = \Sigma_{i=1}^{n}(a_i + d_i) \tag{8}$$

where a_i and d_i are the link length and the joint offset, respectively. This performance index should have a large reachable workspace volume and a small link length sum. That is, it exhibits better performance when the value is smaller.

3.2 Global conditioning index (GCI)

The condition number of the Jacobian matrix is a performance index to measure dexterity. This refers to the determination of the kinematic solution that minimizes the delivery of velocity errors from the joint of a robot manipulator to the end-effector.[18] The definition of the condition number is as follows:

$$k = \frac{\sigma_{max}(J)}{\sigma_{min}(J)} \tag{9}$$

where $\sigma_{max}(J)$ and $\sigma_{min}(J)$ are the maximal singular value and the minimal singular value of the Jacobian matrix, respectively. Since the condition number is the local dexterity measured at a certain location, a method of measuring the dexterity for the entire workspace is necessary.

The GCI was proposed by G. Gosselin and J. Angeles to measure the robot manipulators' global behaviors, and is defined as follows:[20]

$$GCI = \frac{\int w^{1/k} dW}{\int w dW} \tag{10}$$

where W is a workspace defined in the Cartesian space.

The general serial manipulators' workspaces can be expressed more easily in joint spaces than in the Cartesian space, and are defined as follows:

$$GCI = \frac{\int_R 1/k|\Delta| d\theta_n \cdots d\theta_2 d\theta_1}{\int_R |\Delta| d\theta_n \cdots d\theta_2 d\theta_1} \tag{11}$$

where R is the workspace defined in the joint space.

Since a large GCI means that the dexterity in the entire workspace is good, the GCI should be maximized.

3.3 Modified dynamic conditioning index (MDCI)

The DCI is a dynamic isotropic measure proposed by O. Ma and J. Angeles.[14] When the generalized inertia matrix M (n × n matrix) of a robot manipulator is in the following form, it is said to be dynamically isotropic.

$$\mathbf{M} = \sigma \mathbf{1} \tag{12}$$

where n is the DOF, σ is a positive scalar, and 1 is an $n \times n$ identity matrix.

Since generalized inertia matrices are configuration dependent, they cannot maintain isotropy during the entire motion trajectory. Therefore, they should be designed to be as close to isotropy as possible, and the DCI has been quantitatively defined to that end.

$$\mathrm{DCI} \equiv \frac{1}{2}\mathbf{d}^T \mathbf{W} \mathbf{d} \tag{13}$$

where **W** is a diagonal weighting matrix, and **d** is a vector consisting of the upper triangular components of matrix **D**. Matrix **D** is the definition of the difference between the generalized inertia matrix and the isotropic matrix.

$$\mathbf{D} \equiv \mathbf{M} - \sigma \mathbf{1} \tag{14}$$

where M is the generalized inertia matrix, and d is an $n(n+1)/2$-dimensional vector in the following form:

$$\mathbf{d} \equiv [\boldsymbol{I}_{11} - \sigma \quad \cdots \quad \boldsymbol{I}_{nn} - \sigma \quad \boldsymbol{I}_{12} \quad \cdots \quad \boldsymbol{I}_{1n} \quad \boldsymbol{I}_{23} \quad \cdots \quad \boldsymbol{I}_{n-1,n}]^T \tag{15}$$

The DCI as shown by Eq. (14) is to quantify the difference between the generalized inertia matrix and the isotropic matrix. Therefore, when the value of the DCI is smaller, the matrix is closer to dynamic isotropy, and minimizing this index can lead to a better design; however, actually designing a manipulator as shown by Eq. (12) is very difficult. Making manipulators for robots that require high DOF may be impossible. In general, as the location of a link moves from the base to the end-effector, the mass and inertia moment of the link become smaller, and making diagonal matrix forms is mechanically more difficult. Therefore, rather than designing robot manipulators to have isotropic matrices, minimizing changes in the sizes of the mass and inertial moment of the link while working along the given path is more practical. This is also helpful in terms of energy, because larger changes require larger changes in the torque for driving.

The modified DCI uses the (decoupled) inertia matrix that was made by mathematically decoupling the generalized inertia matrix by congruence transformation.[21] The Decoupled Inertia Matrix (DIM), in the form of a diagonal matrix, is as follows (where, N_k is the kth diagonal element of the DIM):

$$\mathbf{DIM} = \begin{pmatrix} \boldsymbol{N}_1 & \cdots & \mathbf{0} \\ \cdots & \cdots & \cdots \\ \mathbf{0} & \cdots & \boldsymbol{N}_n \end{pmatrix} \tag{16}$$

The modified DCI was designed to quantitatively measure changes in the size of the N_k in the DIM and its definition, as shown by Eq. (19).

$$\mathrm{MDCI} \equiv \frac{1}{2}\boldsymbol{d}_N^T \boldsymbol{d}_N \tag{17}$$

where d_N is an n-dimensional vector, and its elements are as follows:

$$\boldsymbol{d}_N \equiv [\delta N_1 \quad \delta N_2 \quad \cdots \quad \delta N_{n-1} \quad \delta N_n]^T \tag{18}$$

$$\delta N_k = \max_{t \in (t_0, t_f)} N_k - \min_{t \in (t_0, t_f)} N_k \tag{19}$$

4. Methodology

Optimal design is aimed at reaching the optimal geometric configuration according to objective functions and constraints. Serial type 7 DOF manipulators are designed to have mechanically wide workspaces and agile workability, and those link parameters that affect the mass and inertial momentum of the manipulators are dynamically optimized for the enhancement of energy efficiency while the robot is working. In this paper, the most general genetic algorithm was used, because the author is more interested in the formulations for design optimization than in the efficiency of the optimization algorithms.

4.1 Design process

Designs that are not systematic cause several defects, such as unnecessary increases in power to the robot, workspaces that are not appropriate for work, or unstable systems. Therefore, kinematic/dynamic optimization should be performed from the initial design stage, and this process is shown in Fig. 2.

The most important factor in the design process is identifying the performance that fits the purpose, while defining the variables, objective functions, and constraint conditions that affect the performance. The detailed contents of this are set forth under sections 4.2 and 4.3.

4.2 Definition of design parameters

If the length, mass and inertia of the link are set as the design parameters, they will not be suitable for actual applications, because the

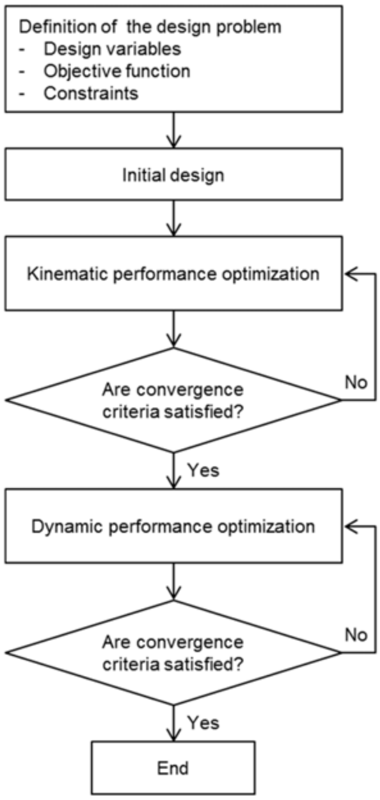

Fig. 2 Design process of a robot manipulator

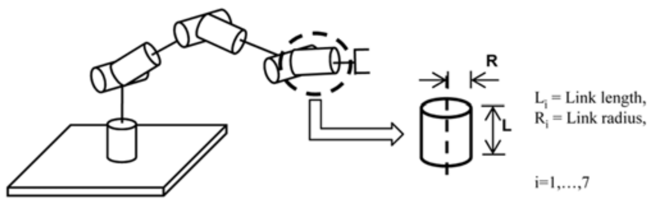

Fig. 3 Link parameters of the 7 DOF robot manipulator

manipulator will not be able to respond to the changes in the mass and inertia following changes in the length. If the links are assumed to be cylinders, the mass (m) of a link can be expressed as the product ($m = \rho * V$) of the density (ρ) and the volume (V), where the volume (V) can be calculated by using the length (L) and radius (R) of the cylinder ($V = \pi * R2 * L$). Therefore, the lengths and radius of the cylinders were set as the design parameters, so that the manipulator can continuously respond to the changes of the design parameters.

4.3 Formulation of performance optimization

The kinematic performance indices and dynamic performance indices were used for optimization to determine the values of the link parameters of the robot manipulator defined previously. The performance indices used to obtain the optimal kinematic performance are the SLI and the GCI. The SLI can be regarded as measuring the efficiency of the work for the entire workspace, and should be minimized. Therefore, the optimization for the determination of the values of those link parameters that affect kinematic performance is as follows:

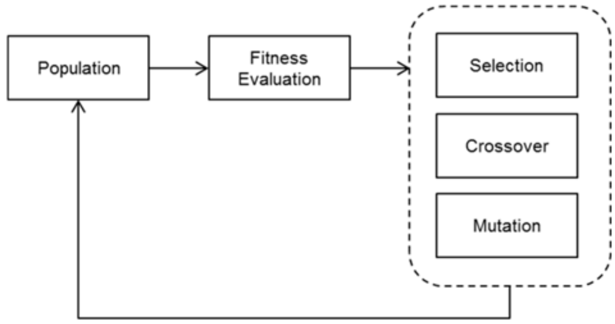

Fig. 4 Diagram of the Genetic Algorithm

Find $L_1, R_2, L_3, R_4, L_5, R_6, L_7$

Objective function min SLI, max GCI

subject to $L_i \in [L_{i,min}, L_{i,max}]$, $R_j \in [R_{j,min}, R_{j,max}]$
$i = 1, 3, 5, 7$, $j = 2, 4, 6$

The performance indices used to optimize the dynamic performance of robots are the MDCI. The MDCI is to quantify changes the state of inertia while a robot manipulator performs a task. Therefore, if the change of state of inertia is getting smaller, then the size of the actuator torque can be reduced. That is, the value of MDCI should be minimized for optimization. The KE (Kinetic Energy) of robot manipulators used only as a tool to compare before and after, not as the objective function for optimization. To maintain the link parameters obtained through the kinematic performance optimization, the optimization should be progressed. Therefore, the optimization to determine the values of those link parameters that affect the dynamic performance is as follows:

Find $R_1, L_2, R_3, L_4, R_5, L_6, R_7$

Objective function min MDCI

Subject to $m_{total,min} < \Sigma_{i=1}^{7} m_i < m_{total,max}$
$m_{i,min} < m_i < m_{i,max}$ $i = 1, \ldots, 7$

4.4 Genetic algorithm

The genetic algorithm[15] is an optimization search algorithm developed by Holland, and based on the principles of the survival of the fittest and natural selection, which are the laws of natural evolution argued by Darwin. The principle of this algorithm is the imitation of the genetic processes in the natural world, to repeatedly perform processes to find more suitable conditions through operations like selection, crossover, and mutation. Those things with structures similar to those of chromosomes, which are biological genetic factors (as shown in Fig. 4), evolve toward better conditions, so that optimal solutions can be found as individuals with inappropriate traits are gradually eliminated in the processes of evolution.

While the existing optimization techniques have local search processes through movements from one point to another, the Genetic Algorithm forms a population of many design points to conduct

Table 2 Kinematic performance optimization results

		Initial	Optimal
Link parameters	L1	0.15 m	0.15 m
	R2	0.06 m	0.06 m
	L3	0.15 m	0.16 m
	R4	0.05 m	0.05 m
	L5	0.15 m	0.16 m
	R6	0.05 m	0.04 m
	L7	0.15 m	0.1 m
Objective function	SLI	0.092	0.087
	GCI	0.053	0.055

Table 3 Dynamic performance optimization results

		Initial	Optimal
Link parameters	R1	0.06 m	0.059 m
	L2	0.15 m	0.134 m
	R3	0.06 m	0.054 m
	L4	0.14 m	0.138 m
	R5	0.05 m	0.042 m
	L6	0.14 m	0.12 m
	R7	0.04 m	0.036 m
Objective function	MDCI	1.121	0.691
Kinetic energy		785.968	642.807

searches for many design points simultaneously, thereby utilizing information on wider design. In this way, the probability for the results to converge on the globally optimal point is much higher than that of the existing methods. In addition, the Genetic Algorithm is suitable for the optimization problem of complicated and diverse environments, because it uses the direct search method with only objective functions and the values of limiting conditions, without the necessity of any additional pieces of information.

5. Optimal link parameters design

In this section, 7 DOF robot manipulators' link parameters are optimally designed using the optimization method presented earlier. A total of two optimizations were performed; first, the length of the links is optimized using the kinematic performance indices. Second, the energy efficiency is enhanced by optimizing the link mass-inertia using dynamic performance indices.

5.1 Optimization of kinematic performance indices

Seven link parameter values corresponding to the link lengths have been optimized to minimize the SLI, while maximizing the GCI. This optimization problem is defined as follows:

Find $L_1, R_2, L_3, R_4, L_5, R_6, L_7$

Objective function min SLI, max GCI

Subject to $0.15\text{m} \le L_1 \le 0.16\text{m},\ 0.06\text{m} \le R_2 \le 0.07\text{m},$
$0.14\text{m} \le L_3 \le 0.16\text{m},\ 0.04\text{m} \le R_4 \le 0.05\text{m},$
$0.14\text{m} \le L_5 \le 0.16\text{m},\ 0.04\text{m} \le R_6 \le 0.05\text{m},$
$0.1\text{m} \le L_7 \le 0.15\text{m}$

The initial design parameters were selected arbitrarily in the range of constraints. After performing optimization using the Genetic Algorithm, the results (Table 2) can be obtained.

Upon reviewing the optimization results, it can be seen that the SLI was improved by approximately 5.4%, and the GCI was improved by approximately 3.6%.

5.2 Optimization of dynamic performance indices

To obtain the optimum distribution of the link masses while maintaining the link parameters obtained through the optimization kinematic performance indices, optimizations that minimize the DCI and the KE have been performed. This optimization problem is defined as follows:

Find R1, L2, R3, L4, R5, L6, R7

Objective function min MDCI

Subject to $20 < \Sigma_{i=1}^{7} m_i < 25$
$3.6 < m_1 < 4.5$
$3.4 < m_2 < 4.25$
$3.2 < m_2 < 4$
$2.8 < m_4 < 3.5$
$2.6 < m_5 < 3.25$
$2.4 < m_6 < 3$
$2.0 < m_7 < 2.5$

Upon reviewing the optimization results, it can be seen that as the total mass was reduced from 26.7 kg to 20.6 kg, the MDCI was improved by approximately 38.3%, and the KE was improved by approximately 18.2%.

6. Conclusion

In this paper, the kinematic performance and dynamic performance of 7 DOF robot manipulators were analyzed to optimize those link parameters that affect the performance. The purpose of this optimization was to create a robot with mechanically wide workspaces and agile workability, and dynamically ensure that the energy efficiency is always improved while the robot is working. To this end, the SLI indicating the efficiency for workspaces and the GCI used for measuring the dexterity of workspaces were used as kinematic performance indices. The MDCI was used as a dynamic performance index in this design, so that robot manipulators' mass-inertia matrices were appropriately distributed for the enhancement of energy efficiency, and the performance was evaluated through KE. For the presented optimization problem, a Genetic Algorithm was used, so that the method would be sturdy against many of the parameters and high non-linearity, and would not fall in the locally optimum points. This method should be helpful in theoretically designing those parameters that have already been designed, while relying on experience thus far in the initial conceptual design stage in 7 DOF manipulator designs. In addition, this method can prevent the actuator with the largest effects on robot performance from becoming bigger than its required specification, when it is selected.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Trade, Industry & Energy and the Korea Evaluation Institute of Industrial Technology (KEIT) with the program number of "10060110" and by the Ministry of Trade, Industry, and Energy, Korea, under the Industrial Foundation Technology Development Program supervised by the Korea Evaluation Institute of Industrial Technology (grant number 10041827, Development on S/W Robot Control for Fast Real-time, Flexible and Open Platform supporting 20Khz control frequency and portability).

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