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Multi-Agent Framework for Kinematics Process of Redundant Multi-Link Robots

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Abstract: This paper proposes a framework of a distributed kinematics process model applied to multi-link robots. In the framework, hardware modules which consists of joints and links are defined as joint components of robotic systems, then kinematics models are composed of a set of the local kinematics Agents (LKAs) which are software module to compute the localized direct and inverse kinematics. Kinematics of robotic systems is resolved by the localized kinematics calculation of LKAs for an end effecter to a target position and an information exchange among LKAs. The proposed framework has been applied to case study of the inverse kinematics problems of 7 degree of freedom redundant multi-link robot manipulator.

Keywords: Kinematics, Redundant, Multi-Link Robot, Multi Agent System

1 INTRODUCTION

The latest decade, practical use of robot technologies has been anticipated not only for industries but also for human life support[1]. Robotic technologies have been cultivated so far within practical industrial applications as a useful article. It is, however, not always in the case of human life support robots because of the complicated versatility of tasks, users, and environments.

Human life environments are not tailored for robots still less than for their work, and robot work would be so versatile. The situation would be also versatile so as that, for example, working situation would differ from the former ever task to be provoked. It could not be estimated so it is eventful. Above all, it is required that a typical robot user who are unfamiliar robotic technologies is able to operate robots under the complicated situation.

In order to deal with these difficulties, intelligent robot is required to provide an appropriate support for robot users who have to operate robots and to make motion planning. The term "intelligent" here refers to induce the change for the variation. Because it is considered that behavior appropriate for variation embodies a sort of intelligent, and that the root of its is to change oneself for the variation.

The purpose of this study is to develop a systematic methodology for intelligent robot system that takes control of itself to make a support for robot users. As the first approach for the purpose, this study investigates a framework of kinematics process model by means of multi-agents system concept (MAS in short). MAS applications has been published in terms of mobile robots[2] and manipulator control[3]. Despite of the kinematics constraint can not be disregarded, MAS based kinematics process is little discussed for universal robotic systems. This paper presents a framework of kinematics process system based on MAS and the detail design of the agents as well as the kinematics sequence. The possible impact of the improved robotic systems is confirmed through the case study.

2 AGENT BASED KINEMATICS PROCESS MODEL

2.1 Framework of kinematics process model

Multi-linked robots are composed of the parts, such as effectors, links, and prismatic or rotational joints. Especially, a pair of joint and adjacent link is a basis of the description of the kinematics properties [4]. This study considers effectors and the pairs of joint/link as a unit component, as illustrated in Figure 1, and corresponds the kinematics process called agent to the unit components. The kinematics solution process is constructed by assembling the agents in accordance with robot mechanism.

There are two types of agents called Local Kinematics Agent (LKA) and Effect Point Agent (EPA). LKA is in charge of the kinematics process for the pairs of joint and link. LKA calculates the rotation angle corresponding to joints for the deviation between the target and the current position of effector, and transmits the joint motion to other LKA located at the tip side of robots. EPA represents the effector, and it calculates the deviation between the current position of effector and its target point.

As shown in Figure 1, the kinematics solution system is configured by associating with the Input/Output relation between LKAs and EPA, and the result of this, LKA and EPA processes are directed by the closed information flow. The kinematics solution is asymptotically obtained as the robot posture in respect to the effector target position.

The feature of this system is to not define explicitly overall direct kinematics model differ from other component type approach[5]. Overall kinematics solution model or function is not formulated until LKM and EPA is related to the each other. Reconfigurable system can be realized by the addition or the remove of LKA.

2.2 Outline of local kinematics

The block diagram of LKA is illustrated in Figure 2. It represents LKA of the j-th joint from the base. LKM consists of main three parts which are called Local Direct Kinematics process, Local Inverse Kinematics process, and Joint State variables.

The Joint State variables are the data to represent joint condition. They are joint position $\mathbf{p}_j$, joint axis $\mathbf{a}_j$ and joint rotation angle θ_j. These values are initialized according to a preliminary position and posture of robots. The Local Inverse Kinematics calculates the rotation angle to be moved for minimizing the deviation between the current position and the target position of effector. The Local Direct Kinematics process consists of two transform operations and a composition operation. The transform operation transforms the Joint State variables in accordance with other joint motion located at the base side. The composition operation composes the motion of oneself and the synthetic motion composed of the previous joints.

For example, the Joint State variables of joint j are transformed by the synthetic motion $\mathbf{R}_j$ and $\mathbf{L}_j$ which are rotation and translation, respectively. Where the motion of joint j is $\mathbf{R}_j$ and $\mathbf{L}_j$, the synthetic motion ${}^1\mathbf{R}_j$, ${}^1\mathbf{L}_j$ is made by composing the motion ${}^1\mathbf{R}_{j-1}$, ${}^1\mathbf{L}_{j-1}$ and the motion $\mathbf{R}_j$, $\mathbf{L}_j$. The synthetic motion is sent to next LKA, and it is composed one after another towards LKAs located at the tip side. EPA refers to effector and its process is the same as LKA in the composition except for the process to obtain the deviation between the current position and the target position of effector instead of Local Inverse Kinematics process. The current position of effecor and the deviation are sent to all of LKA for invoking the Local Inverse Kinematics process.

2.3 Kinematics solution process

The overall kinematics is executed by the successive approximations of LKA process for the deviation calculated by EPA. The local direct kinematics of LKA transforms value of the Joint State variables based on synthetic motion ${}^1\mathbf{R}_{j-1}$ and ${}^1\mathbf{L}_{j-1}$. These are the synthetic motion from the base to joint j-1, for instance in Figure 3. The Joint State variables, therefore, are correctly transformed and the direct kinematics properties are satisfied for the overall robots.

In the j-1degrees of freedom robots, EPA located at j-th from the base transforms the Effector State variables by ${}^1\mathbf{R}_{j-1}$ and ${}^1\mathbf{L}_{j-1}$. The effector position $\mathbf{P}_E$ and the deviation $\Delta\mathbf{P}_G$ sent from EPA to each of LKA and the rotation angle is calculated to minimize the deviation by LKA. The rotation angle accumulates as the joint angle θ_j. When the above processing is repeated at proper times, $\Delta\mathbf{P}_G$ is converged on zero and θ_j is converged on a solution of inverse kinematics problem for the target position $\mathbf{P}_G$.

${}^1\mathbf{R}_{j-1}$, ${}^1\mathbf{L}_{j-1}$, $\mathbf{P}_E$ and $\Delta\mathbf{P}_G$ are obtained from the base side LKA and EPA. Then, ${}^1\mathbf{R}_j$ and ${}^1\mathbf{L}_j$ can be determined from only the Joint State variables Therefore, the direct kinematics can be distributed by LKA. LKA is the same process for all joints. The kinematics process can be composed by attaching or detaching LKA in accordance with the structure of robots and by preliminary Joint State variables.

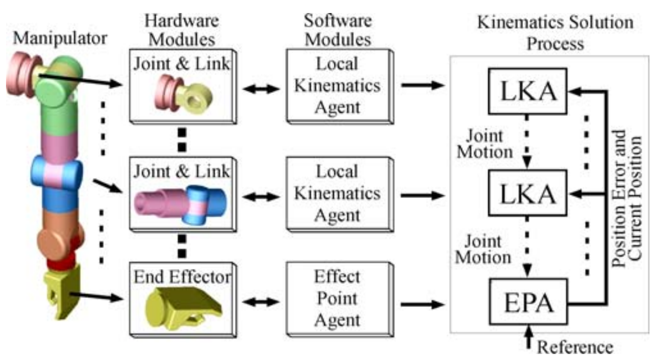

Fig. 1 Agent type kinematics solution model

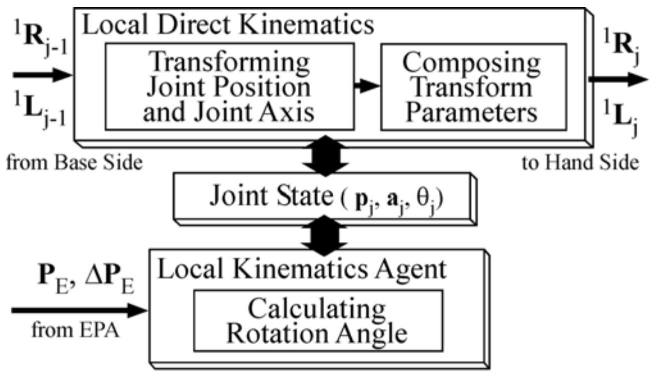

Fig. 2 Block diagram of j-th LKA

3 LOCAL KINEMATICS CALCULATION

3.1 Local inverse kinematics

The Local Inverse Kinematics process calculates the deviation angle to minimize the distance between effector and target position. The deviation angle can be represented by the magnitude of vector which is obtained as a joint axis projection of the deviation angle vector. As shown in Figure 4, the deviation angle vector is a plane angle formed between $\mathbf{g}_j$ and $\mathbf{e}_j$. The deviation angle $\Delta\theta_j$ is expressed in the following equation (1).

$$\Delta\theta_j = \begin{cases} 0 & |\mathbf{e}_j \times \mathbf{g}_j| = 0 \\ \mathbf{B} \cdot \mathbf{a}_j \cos^{-1} C & |\mathbf{e}_j \times \mathbf{g}_j| \neq 0 \end{cases} \tag{1}$$

$$\mathbf{B} = \frac{\mathbf{e}_j \times \mathbf{g}_j}{|\mathbf{e}_j \times \mathbf{g}_j|}, \qquad C = \frac{\mathbf{e}_j \cdot \mathbf{g}_j}{|\mathbf{e}_j| \cdot |\mathbf{g}_j|}$$

$$\mathbf{e}_j = \mathbf{P}_E - \mathbf{p}_j, \qquad \mathbf{g}_j = \mathbf{e}_j + \Delta\mathbf{P}_G$$

Here, $\mathbf{P}_E$ and $\Delta\mathbf{P}_G$ are the information provided from EPA. Also, $\mathbf{e}_j=\mathbf{0}$ and $\mathbf{g}_j=\mathbf{0}$ give singular points of the equation (1), but it is the case of $\mathbf{P}_E+\Delta\mathbf{P}_G=\mathbf{P}_j$ or $\mathbf{P}_E=\mathbf{p}_j$, hence singularity is not noticed in a practical range. Effector motion is a superposition of each joint motion. $\Delta\theta_j$ is approximate value, so, an appropriate proportional constant $K_j(<1)$ is introduced, finally the deviation angle is calculated as $K_j\Delta\theta_j$.

3.2 Local direct kinematics

The local direct kinematics transforms the Joint State variables of LKA in accordance with the synthetic motion sent from the base side LKA. Here, ${}^1\mathbf{R}_{j-1}$ and ${}^1\mathbf{L}_{j-1}$ represent the synthetic motion composed from the base through to the joint j-1. The joint j transforms own Joint State variables by the motion. When the joint position is $\mathbf{P}_j$ and the joint axis is $\mathbf{a}_j$ before transformation, by the motion of ${}^1\mathbf{R}_{j-1}$ and ${}^1\mathbf{L}_{j-1}$, the Joint State variables are transformed as follows.

$$\begin{cases} \tilde{\mathbf{p}}_j = {}^1\mathbf{R}_{j-1}\mathbf{p}_j + {}^1\mathbf{L}_{j-1} \\ \tilde{\mathbf{a}}_j = {}^1\mathbf{R}_{j-1}\mathbf{a}_j \end{cases} \tag{2}$$

After transformation, for new position $\tilde{\mathbf{p}}_j$ and axis $\tilde{\mathbf{a}}_j$, the rotation $\mathbf{R}_j$ represents as follow from Rodriguez equation when the joint j rotates $\Delta\theta_j$.

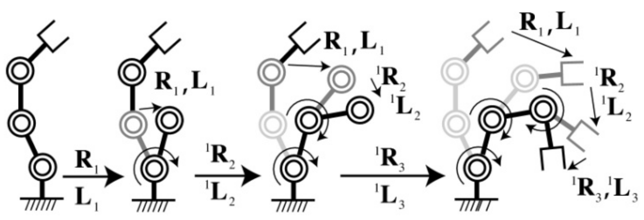

Fig. 3 Direct kinematics calculating process

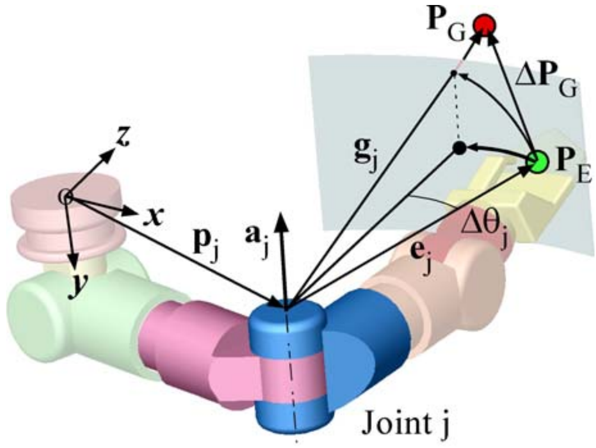

Fig. 4 Schematic of the local inverse kinematics

$$\mathbf{R}_j = \mathbf{E} + [\tilde{\mathbf{a}}_j \times]\sin\Delta\theta_j + [\tilde{\mathbf{a}}_j \times]^2(1-\cos\Delta\theta_j) \tag{3}$$

Where, $\mathbf{E}$ is a unit matrix, $[\tilde{\mathbf{a}}_j \times]$ is an alternating matrix which is satisfied $\tilde{\mathbf{a}}_j \times \mathbf{p} = [\tilde{\mathbf{a}}_j \times]\mathbf{p}$ with an arbitrary vector $\mathbf{p}$. As shown in Figure 4, $\tilde{\mathbf{a}}_j$ is an axis of rotation passing through $\tilde{\mathbf{p}}_j$. The rotation generated by the joint j with angle $\Delta\theta_j$ transforms an arbitrary point $\mathbf{p}$ and axis $\mathbf{a}$ as follows.

$$\begin{cases} \tilde{\mathbf{p}}_j = \mathbf{R}_j(\mathbf{p} - \tilde{\mathbf{P}}_j) + \tilde{\mathbf{P}}_j = \mathbf{R}_j\mathbf{P} + (\mathbf{E} - \mathbf{R}_j)\tilde{\mathbf{P}}_j \\ \tilde{\mathbf{a}} = \mathbf{R}_j\mathbf{a} \end{cases} \tag{4}$$

The transformation of $\mathbf{p}$ at equation (4) can be performed by only rotation $\mathbf{R}_j$ around the origin and translation $(\mathbf{E} - \mathbf{R}_j)\tilde{\mathbf{P}}_j$. Consequently, the motion ${}^1\mathbf{R}_j$ and ${}^1\mathbf{L}_j$ which are the composition of $\mathbf{R}_j$, $(\mathbf{E} - \mathbf{R}_j)\tilde{\mathbf{P}}_j$ and ${}^1\mathbf{R}_{j-1}$ and ${}^1\mathbf{L}_{j-1}$ is as follows.

$$\begin{cases} {}^1\mathbf{R}_j = \mathbf{R}_j\, {}^1\mathbf{R}_{j-1} \\ {}^1\mathbf{L}_j = \mathbf{R}_j\, {}^1\mathbf{L}_{j-1} + (\mathbf{E} - \mathbf{R}_j)\tilde{\mathbf{P}}_j \end{cases} \tag{5}$$

From equation (3) and (4), $\mathbf{R}_j$ and $(\mathbf{E} - \mathbf{R}_j)\tilde{\mathbf{P}}_j$ are determined by only Joint State variables. As ${}^1\mathbf{R}_{j-1}$ and ${}^1\mathbf{L}_{j-1}$ are received from LKA located at the base side, highly independent MAS based kinematics process is available.

4 CASE STUDY

Kinematics solution of 7 d.o.f manipulator

To investigate the proposed framework, the inverse kinematics problem of 7 d.o.f manipulator is executed as illustrated in Figure 5. The initial Joint State variables are show in Figure 5. All of joint angles are set zero at the initial posture, and the end effector is placed on the position (400, 400, 0).

For each iteration by direct and inverse kinematics, the transition of each joint angle is shown in Figure 6. Firstly, some of joint angles had a large value, then these gradually converged a steady value. The transition of position error from the target position is shown in Figure 7. The position error gradually becomes small, after 23 times of iteration processes it is less than 1 mm.

5 CONCLUSION

This paper has presented the framework of kinematics resolution system based on MAS concept and the detail design of the agents as well as the kinematics computation sequence of the system. The feasibility with the possible impact of the improved robot systems has been confirmed through the case study. Conclusions are as follows.

1) Considering a module constructed from joint and link component of robot, defining the Local Kinematics Module (LKA) related to the component and the Effect Point Module (EPA) related to end effector, and the configuration method of a decentralized kinematics calculation model composed of LKA and EPA has proposed.

2) Implementability of decentralizing the calculation of LKA and EPA with respect to each module and calculating the direct and inverse kinematics of manipulator by iterative calculation has been shown.

3) The proposed method has been applied to the inverse kinematics problem of 7 d.o.f manipulator. The computability of the kinematics solution using the proposed calculation model and flexibly with various tasks has been shown.

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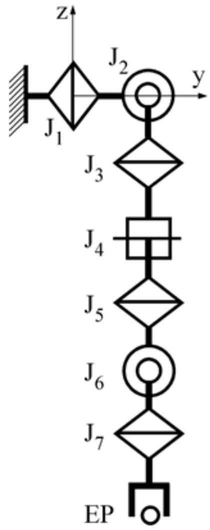

Joint	Initial Joint State Position	Axis
J_1	(0,61.5,0)	(0,-1,0)
J_2	(0,128.5,0)	(1,0,0)
J_3	(0,128.5,-140)	(0,0,1)
J_4	(30,128.5,-270)	(0,-1,0)
J_5	(0,128.5,-385)	(0,0,1)
J_6	0,128.5,-495)	(1,0,0)
J_7	(0,128.5,-573)	(0,0,1)
EP	(0,125,-693)	

Fig. 5 Seven d.o.f manipulator initial configuration

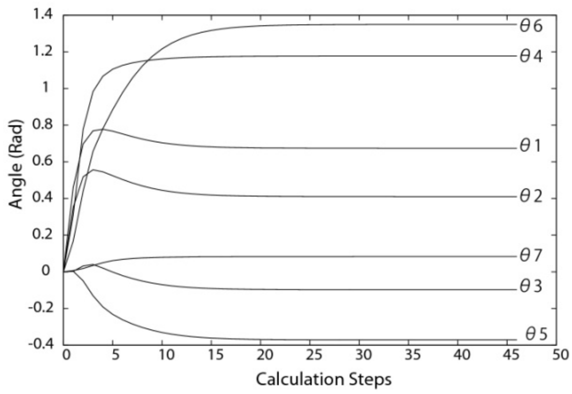

Fig. 6 Calculating result of joint angles

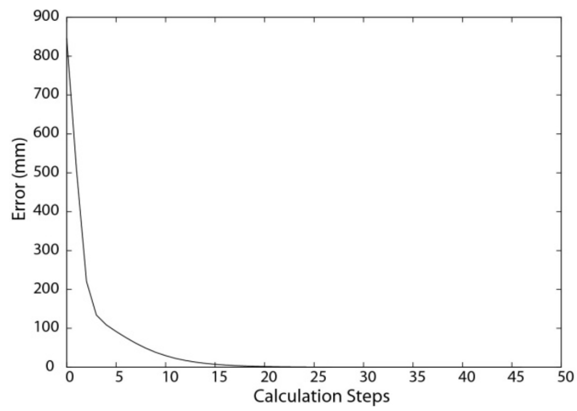

Fig. 7 Position error of end effector