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Self-Collision Detection & Avoidance Algorithm for a Robot Manipulator

Chanhun Park
Korea Institute of Machinery & Materials, Korea

Abstract*— A self-collision algorithm of two arms has been developed for a developed dual arm robot manipulator. Because the developed dual arm robot is supposed to do a job of complex task which needs cooperative motion of two arms. In this complex task, self-collision of two arms can occur. In this paper, developed self-collision avoidance algorithm to prevent the limbs of the dual arm robot from colliding to each other will be introduced. The developed dual arm robot manipulator would be much safe in the situation of self-collision caused by wrong teaching and a breakdown of controller and etc.

***Index Terms*— Self collision, Collision avoidance, Dual arm robot, Cooperative motion, Collision detection.**

I. INTRODUCTION

A dual arm robot manipulator with 6 DOF per arm and 2 DOF per torso was developed for precision assembly of mechanical parts for auto mobiles which cannot be assembled with single arm robot manipulator. This dual arm robot has 3 limbs, a right arm, a left arm and a torso so there are some possibilities of collision to each other in some case of wrong teaching and a breakdown of controller. For this reason, the self-collision avoidance algorithm to prevent the limbs of the dual-arm robot from colliding to each other has been developed and also it will be introduced, in this paper. It takes very much time to calculate the possibility of self-collision with an exact robot model. So, virtual links and virtual spheres concept is introduced to reduce computing time. If the self-collision is predicted, the robot controller can stop the robot motion or make the robot movement slow down.

II. DUAL ARM ROBOT MANIPULATOR FOR COOPERATIVE TASKS

The assembly lines of gear transmission and constant velocity joints are our first targets as shown in figure 1. These two assembly processes definitely need so-called “cooperative task” of two arms of a worker, so single arm robots can’t be applied to these kinds of processes. This is one of the reasons that the major automobile companies keep these processes not-automated. For this purpose, an industrial dual arm robot manipulator has been developed as shown figure 4. Fig. 2 shows the kinematic structure of the developed manipulator which has the torso of 2 DOF and two arms of 6 DOF each. Fig 3 shows sample motions for the cooperation tasks by the developed robot manipulator. Fig 4 shows the picture of the developed dual arm robot manipulator.

Fig.1 Transmission assembly line (left) and the CV Joint assembly line

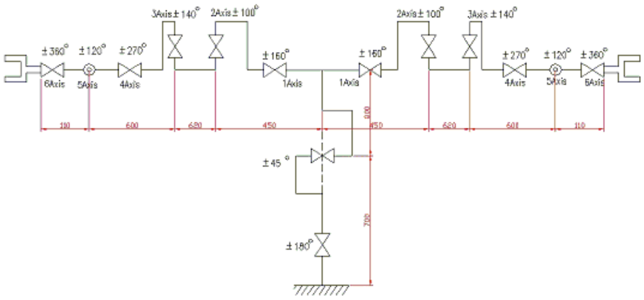

Fig. 2 Kinematic structure of the developed manipulator

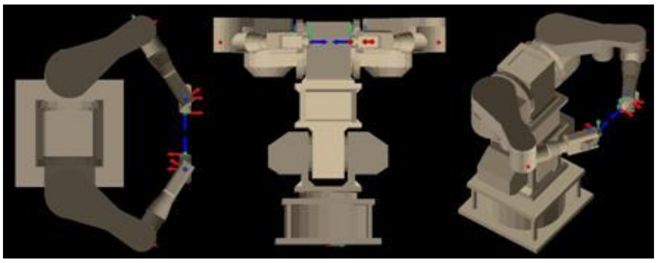

Fig. 3 Configurations for the cooperation task by the developed dual arm robot manipulator

Fig. 4 Developed dual arm robot manipulator

III. COLLISION AVOIDANCE ALGORITHM

There are some possibilities that arms and a torso collide to

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each other in some case of wrong teaching, a breakdown of controller, as shown figure 5. In some complex jobs, the paths of two arms can be crossed or interconnected to each other. When the manipulator is controlled to get a cooperative motion of the two arms, the possibility of two arms is increasing. In these cases, the prediction of self-collision is necessary for safety. The developed self-collision avoidance algorithm can be very useful for this situation. If the self-collision is predicted, the robot controller can stop the robot motion or modify the robot movement to get slow down. For these reasons, the self-collision avoidance algorithm to prevent the limbs of the dual-arm robot from colliding to each other has been developed.

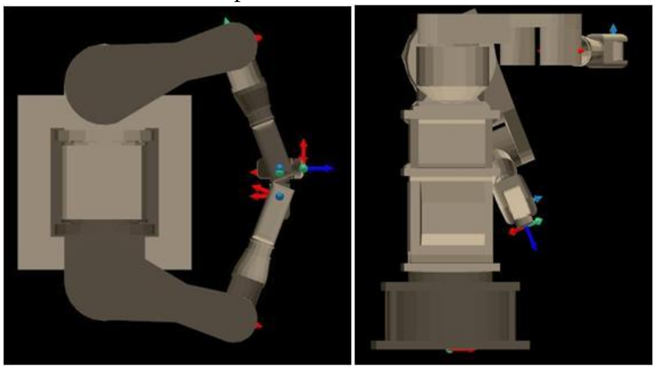

Fig. 5 Examples of self-collisions

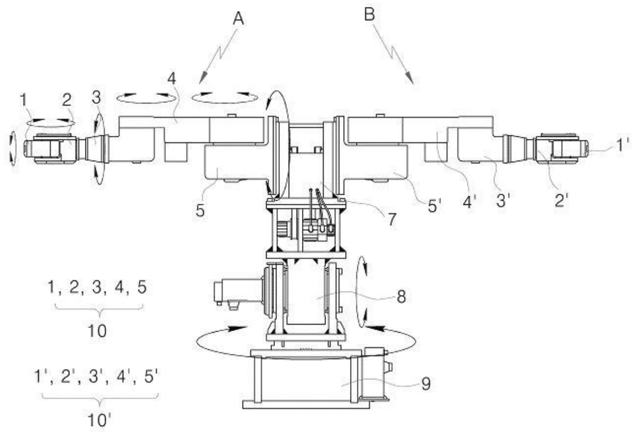

Fig. 6 The exact CAD model of the developed robot

Fig. 6 shows the exact CAD model of the developed dual arm robot manipulator. It takes very much time to predict the possibility of self-collision considering an exact 3D robot model. Dominik Henrich[1][2] tried to predict the collision between the robot manipulator and the human workers using some hierarchical trees composed of 3D polygons representing (or including) the exact model of the robot manipulator. Boolean operation is needed for considering 3D polygons and the collision to each other (Fig. 7). It is possible to predict self-collision but it took so much computing time with their method.

To reduce computing time to predict self-collision, virtual links and virtual spheres concept, as shown in figure 8, is introduced in this paper. The real link (10) can be covered (enveloped) by the virtual link (20). The volume of the virtual link is always bigger than the real link volume. The virtual link is composed of the virtual spheres (21 ~ 27). A virtual sphere is attached to the real link and it covers some parts of the real link. Each virtual sphere has different radius. Virtual spheres are connected to each other and the total virtual spheres can cover (envelope) the real link which compose the virtual link. The position and the radius of the virtual sphere can be controlled to make the virtual link effectively covers (envelopes) the real link shape.

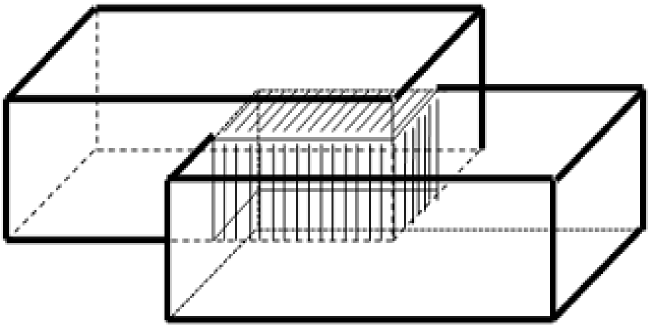

Fig. 7 Collision detection with exact 3D model

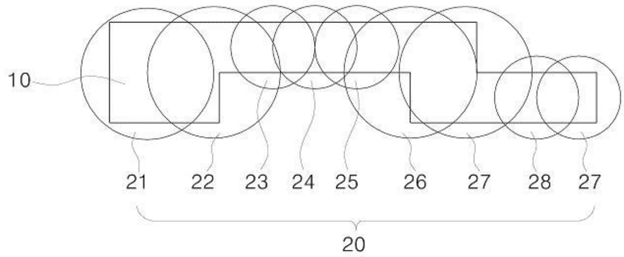

Fig. 8 Exact link, virtual link and virtual spheres

Collision of the links can be predicted considering the collision of the virtual links. Collision of virtual links can be calculated by the consideration of the collision of the virtual spheres of the virtual links. If the distance between the virtual spheres is less than the summation of the radiuses of the two virtual spheres, then it means that the two virtual spheres are in collision, as shown in figure 9. It is not true that the collision of the virtual links means the collision of the real links. Generally speaking, the collision of the virtual links means that the collision of the real links could occur in near future. Of course, the possibility of the collision of the real link would be higher when the robot moves with high speed than when the robot moves with low speed or stops. So, there are many ways to interprete the calculation results on the collision prediction of the virtual links.

Using the concept of the virtual link and virtual sphere, it's easy to calculate the possibility of the collision of the real links. The advantage of this method is that the stability margin for the non-collision condition is only dependent on the radius of the virtual sphere. The bigger radius of the virtual sphere means the bigger stability margin for the non-collision condition. The programmer or the worker with a teaching pendant can vary the collision stability margin controlling the radius of the virtual sphere in real time. For example, in the teaching mode, the possibility of the self-collision by the operator's mistake is higher than in the playback mode. So the bigger stability margin for the self-collision is needed, the operator can set the bigger radius value for the virtual sphere. In the cooperation task for assembly, if the stability margin for the self-collision is set too high, then there would be too much motional limit for the robot motion because the robot is controlled to stop even when the end-effectors are close to each other for cooperation task. So the radius of the virtual spheres has to be set with the lower value for the effective cooperation motion even if there are some possibilities of the self-collision of the end-effectors.

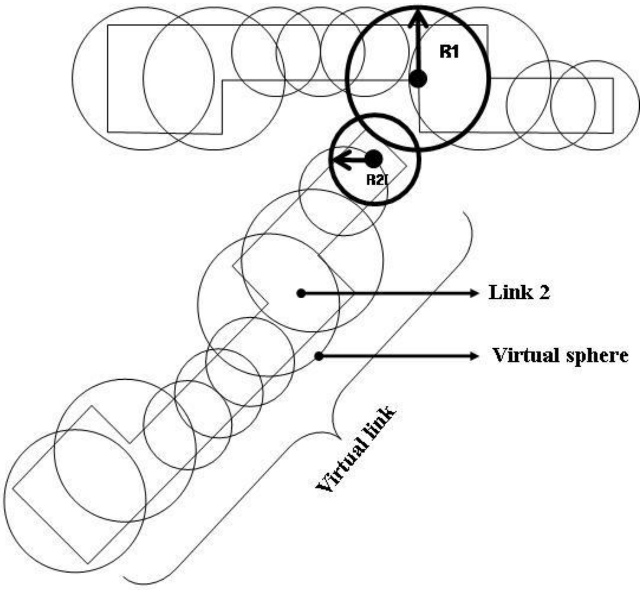

Fig. 9 Calculation method of the collision of the virtual spheres

The proposed method needs less computation power. If the exact 3D model of the dual arm robot is used to predict self-collision, then awfully big number of the virtual spheres has to be used, which means that the computation can't be done in real time. But for general purpose, small numbers of virtual spheres are enough to count the collision possibility. In this research, 5 virtual spheres per one link was used and the collision estimation can be computed in real time, in this paper

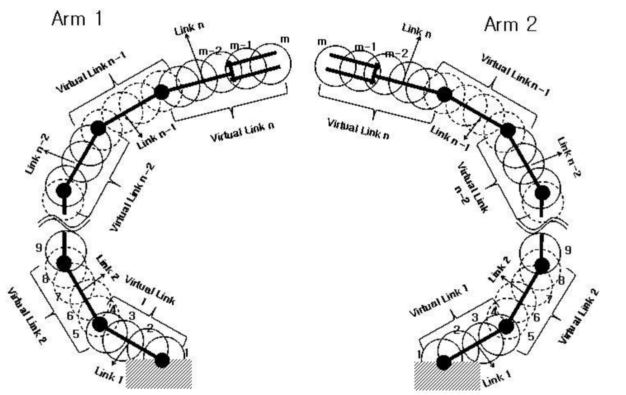

Fig. 10 Example of the virtual link and virtual links for the dual arm robot manipulator

Virtual links and the virtual spheres can be generated in the variety ways. Fig. 10 shows the general case for the dual arm robot manipulator. The number of virtual links is equal to the number of links of the robot. The number of virtual spheres and their radius can be set by the operator using a teaching pendant.

Fig. 11 shows the flow chart to realize the self-collision avoidance algorithm.

- First, the parameters for the virtual links are set including the radius and the number of virtual spheres and the relative locations on the real link.
- Second, the new reference path for the robot motion is generated.
- Third, the forward kinematics is calculated.
- Fourth, the location of every virtual sphere is calculated with respect to the base coordinates.
- Fifth, self-collision is checked. If self-collision is predicted, then the manipulator will be controlled to decelerate and finally stop. If the possibility of self-collision is not predicted, the robot manipulator is controlled to follow the original reference motion profiles and a new motion profile is generated.

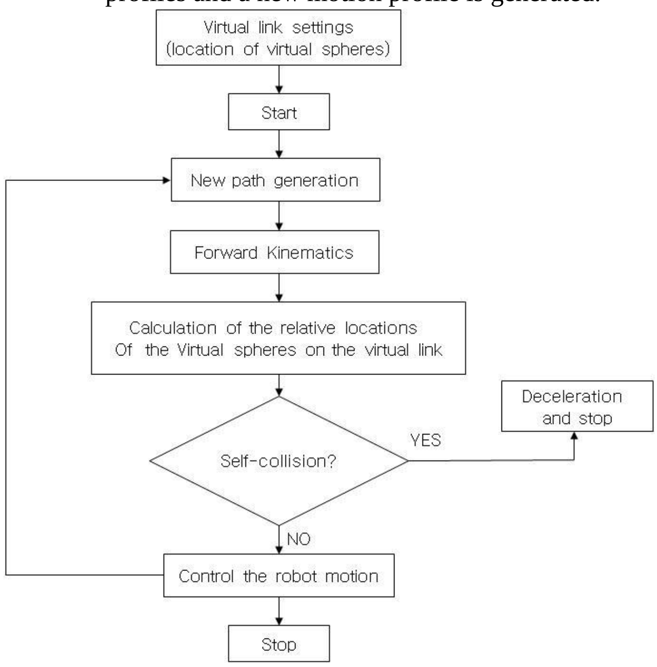

Fig. 11 The flow chart of the collision avoidance

Fig. 12 shows the real robot manipulator and the virtual robot manipulator which is composed of the virtual links (virtual spheres). The left of the each picture shows the 3D CAD model of the real robot and the right of the each picture shows the virtual robot which is composed of the virtual spheres. The virtual spheres for the torso are much bigger than the virtual spheres for the left and right arms. The left arm and the right arm are usually in close distance because they have to do the cooperation jobs for assembly, so the relatively small radius for the virtual sphere is used. Small radius for virtual sphere means low stability margin for self-collision and high motion flexibility for the cooperation jobs. The torso is just for rotating motion and bending motion. As a result, the total workspace of the dual arm robot manipulator is enlarged. In the general cases, two arms are controlled not to be closed to the torso. That's why the bigger radius is used for the virtual spheres for the torso. As a result, there are the big stability margin for the self-collision between the two arms and the torso.

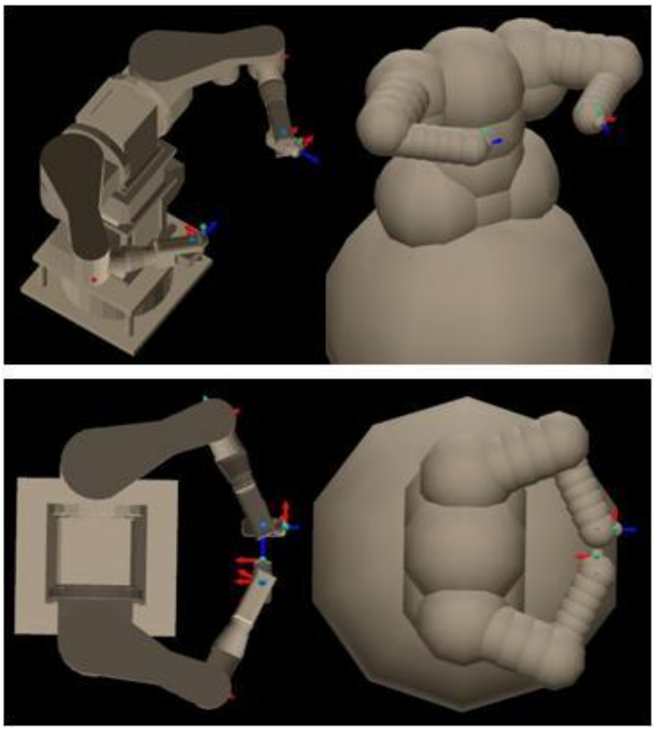

Fig. 12 A real dual arm robot and the virtual dual arm robot

IV. CONCLUSION

Efficient self-collision avoidance algorithm for the dual-arm robot has been developed. This collision detection and avoidance algorithm can be ported into the robot controller because the required computation power is very low. So, developed self-collision detection and avoidance algorithm can be calculated in real time. As a result, the developed dual arm robot manipulator would be much safe in the situation of the self-collision caused by the wrong teaching, a breakdown of controller and etc.

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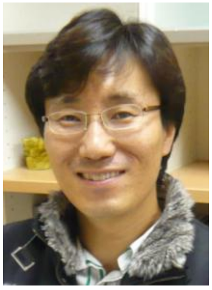

Chanhun Park received PhD degree in Mechanical Engineering from KAIST, KOREA. He has been working for Korea Institute of Machinery and Materials (KIMM), Korea, since 1996, where he is currently a principal researcher. His research fields include design and control of high speed parallel robot system. He is also interested in human-robot cooperation and design and control of dual arm robot manipulator for industrial applications.