# Collision Detection of Robot Manipulator in Cryogenic Environments

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***Abstract***: This paper studies a method how a robot can detect collision between the canister on the end-effector of a robot and a pin of a slot in a rack of the vessel during operating the manipulator of an automatic cryogenic storing vessel which can improve a ratio of survival of a cord blood. The cord blood is kept in liquid nitrogen in the cryogenic vessel. The integrated robot control system for storing a cord blood is developed, which is based on mechanism of SCARA robot. The robot manipulator consists of four axes. To overcome difficulty in detecting collision between canister and the pin of the slot in cryogenic circumstances around -196°C, a collision detection algorithm for the robot manipulator is proposed. To improve performance of the integrated system, the proposed algorithm for the collision avoidance is applied to the end effecter of the robot manipulator.

***Keywords***: Motion control, Collision detection, Robot manipulator, Cryogenic

## I. INTRODUCTION

Many researchers recently have studied to extract adult stem cells from umbilical cord blood and to implant embryonic stem in the body for improvement of human life [1], [2], [3]. The cord blood is used to usefully cure disease such as cancer. Therefore a storing vessel of the cord blood in cryogenic environment is important to keep a ratio of survival of the cell. Storing vessel is divided manual type and automatic type. The ratio of survival is higher than manual type. Because of the ratio of survival, the automatic type is developed and has been operated even if the price of an automatic storing vessel type is 10 times higher than the one of a manual type. In addition, because the work of picking the cord blood up by hand outside is frequent, the ratio of survival is low due to sudden temperature change. We have been developed the automatic type previous study [4]. A collision is occurred in previous study. This study is proposed the algorithm of collision avoidance in cryogenic environment. Because of an electronic sensor can not apply to the environment of liquid nitrogen. This study is accomplished that the method how a robot manipulator can detect collision between the canister and the end effecter of robot manipulator.

## II. DESIGN OF ROBOT

The storing cord blood system consists of cryogenic vessel, robot manipulator, and control PC. Fig. 1 shows inner space of storing vessel's layer and the canister. Each layer consists of 7 rings. The ring consists of three racks. An outer rack has 270 ea slot pin. Middle rack has 149 ea slot pin. Inner rack has 71 ea slot pin. The numbers of total slot pin are 3,430 ea. When storing the cord blood, liquid nitrogen is filled up the top of the ring. The material of the ring and the canister is a stainless steel. A ratio of contraction in z-axis is bigger than x-y plane. Therefore we consider the contraction for a direction of z-axis. So we propose the collision avoidance algorithm for robot manipulator based on collision detection algorithm using the position of z-axis.

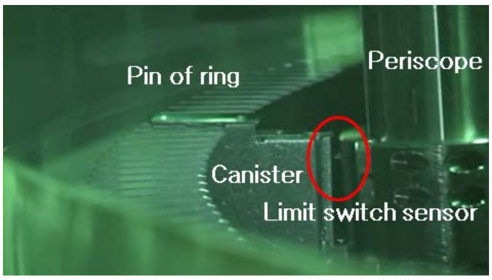


Fig.1. Pins of ring in rack and canister

 

Fig. 2 shows the block diagram of robot manipulator based on mechanism of SCARA robot [5], [6]. The link of manipulators are consists of d_1, l_2, d_2, l_3, d_3, and l_4. The parameter of d_1 is height of storing vessel. The value of l_2 add to l_3 is a radius of major lid. The parameter of l_3 is a radius of minor lid. But the storing vessel should be a sealed structure because of liquid nitrogen is vaporization gas in the normal temperature. Therefore, major lid and minor lid are designed using the structure of the robot manipulator instead of upper cover. Table 1 is D-H parameter of the robot manipulators. Transformation matrixes are as formula (1). The material of the cryogenic vessel and the robot manipulators were made of a stainless steel.

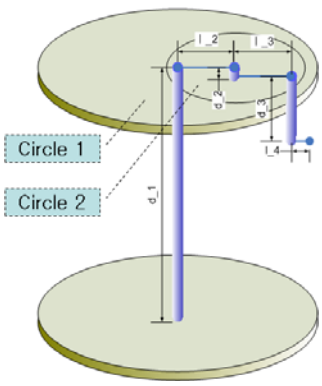


Fig.2. Block diagram of manipulator for SCARA

Table 1. D-H parameter of robot manipulator

| Θ | d | α | a |
|---|---|---|---|
| θ1 | d_1 | 0 | 0 |
| Θ2 | 0 | 0 | l_2 |
| Θ3 | -d_3 | 0 | l_3 |
| 0 | 0 | 0 | l_4 |

$$A_1 = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & d\_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} A_2 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & l\_2\cdot\cos\theta_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & l\_2\cdot\sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & l\_3\cdot\cos\theta_3 \\ \sin\theta_3 & \cos\theta_3 & 0 & l\_3\cdot\sin\theta_3 \\ 0 & 0 & 1 & -d\_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} A_4 = \begin{bmatrix} 1 & 0 & 0 & l\_4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$${}^0A_4 = \begin{bmatrix} \cos(\theta_1+\theta_2+\theta_3) & -\sin(\theta_1+\theta_2+\theta_3) & 0 & (l\_3+l\_4)\cdot\cos(\theta_1+\theta_2+\theta_3)+l\_2\cdot\cos(\theta_1+\theta_2) \\ \sin(\theta_1+\theta_2+\theta_3) & \cos(\theta_1+\theta_2+\theta_3) & 0 & (l\_3+l\_4)\cdot\sin(\theta_1+\theta_2+\theta_3)+l\_2\cdot\sin(\theta_1+\theta_2) \\ 0 & 0 & 1 & d\_1-d\_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

## III. SIMULATION

The robot manipulator consists of four axes. Each axis consists of a rotation of a major lid, a rotation of a minor lid, a rotation of periscope and a linear motion of periscope. Fig. 3 shows the rotation direction of each axis. Motions of manipulators have three patterns for storing. One is rotation motion by major lid and periscope. Another is linear motion by combination of three axes. The other is linear motion of z-axis by ball screw.

Fig. 4 shows a simulation of dynamics using OpenGL program. We know a position of the canister in the storing vessel by the simulation. Fig. 5 shows forward kinematic analysis and inverse kinematic analysis using MATLAB program. Parameters of an existing product were used for the simulation [7].

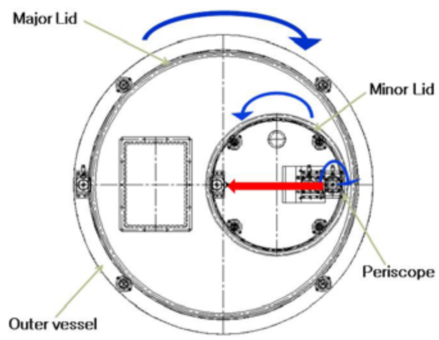


Fig.3. A rotation direction of each axes

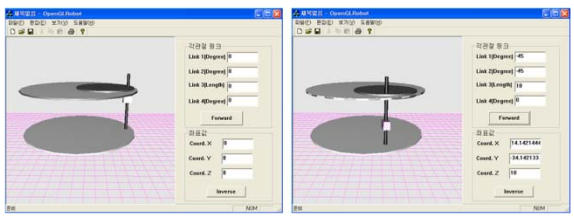

Fig.4. Visual C++ program of OpenGL simulation

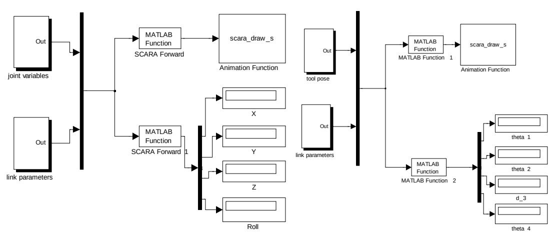

Fig.5. Block diagram of MATLAB simulation

## IV. COLLISION DETECTION ALGORITHM

Fig. 6 shows block diagram of a direction for storing canister. If collision state is occurred, a contact of the limit switch sensor is closed. Fig. 7 shows procedure of a canister for storing procedure. We defined safety area for the robot manipulator. A rotation motion moved by major lid for search a correct ring of address pin. The collision detection algorithm was used for a linear motion by combination of three axes.

Fig. 8 shows a view of the canister and the pin of the slot in the rack. The ratio of contraction as the direction of z-axis is bigger than the x-y plane in cryogenic environment. Therefore we consider the control of manipulator for the direction of z-axis. So we propose the collision avoidance algorithm for robot manipulator based on collision detection algorithm using the position of z-axis. We used two parameters that are length of linear move for the x-y plane and the status of limit switch contact in the end effecter of the hook. Fig. 9 shows each case of the canister position. Case 1 is normal operation. The collision detection is case 2 and case 3. Case 4 is failure canister for storing in rack pin.

The relationship of each case is
- Case1 : Normal linear motion and open contact s/w
- Case2 : Short linear motion and close contact s/w
- Case3 : Short linear motion and close contact s/w
- Case4 : Open contact s/w and open contact s/w

Fig. 10 shows a flowchart of collision detection algorithm. The signal of the limit switch sensor and the position value of AC servo motor's encoder are used. Each manipulator of servo motor is controlled by using MMC board on the control PC. I/O port of MMC board gets a signal of input for contact of limit switch sensor.

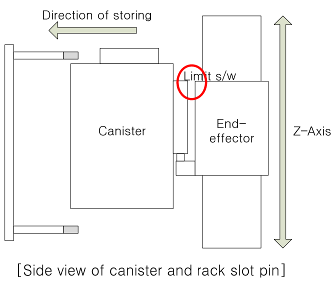


Fig.6. Block diagram of direction for storing

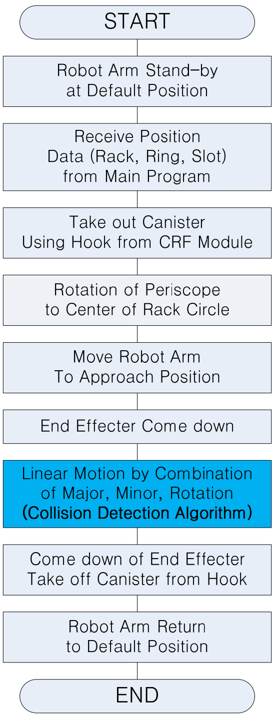


Fig.7. Procedure of a canister for storing

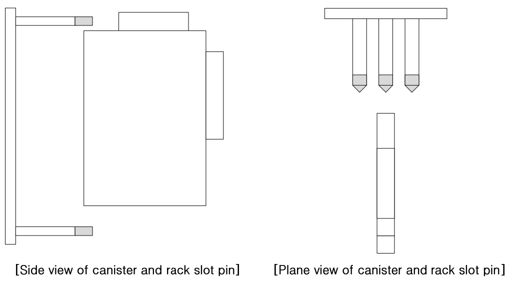


Fig.8. View of the canister and rack slot pin

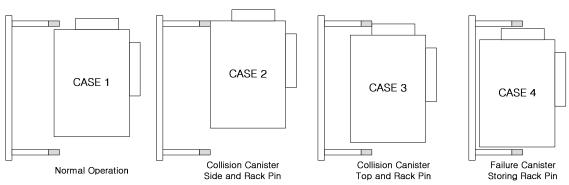


Fig.9. Each cases of the canister position

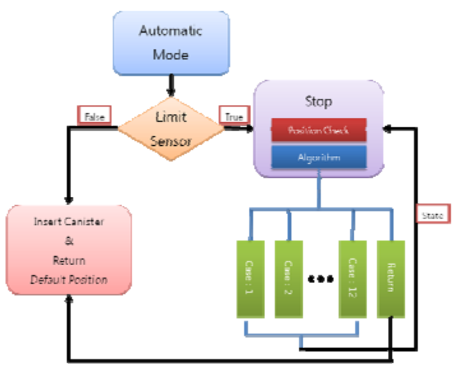


Fig.10. Collision detection algorithm

## V. CONCLUSION

The cryogenic vessel of containing liquid nitrogen for the storing of the cord blood in the canister is needed to precision control. We defined the position of the canister by analyzing of kinematics. The ratio of contraction in liquid nitrogen is bigger than in the air. It is too difficult to measure using visual or other electronic sensors in cryogenic environments. To overcome difficulty to detect collision between the canister and the pin of the slot in the rack of the vessel, the limit switch sensor was designed the hook of the end effecter for robot manipulator. If the canister of the cord blood to enter with abnormal location for storing, the algorithm for the collision avoidance can be modified in the normal location by operating of the limit switch sensor. The canister of the cord blood can be store in the normal position by using this collision detection method.

## ACKNOWLEDGEMENT

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