A Study on the Multi-Joint Rehabilitation System of an Industrial Robot

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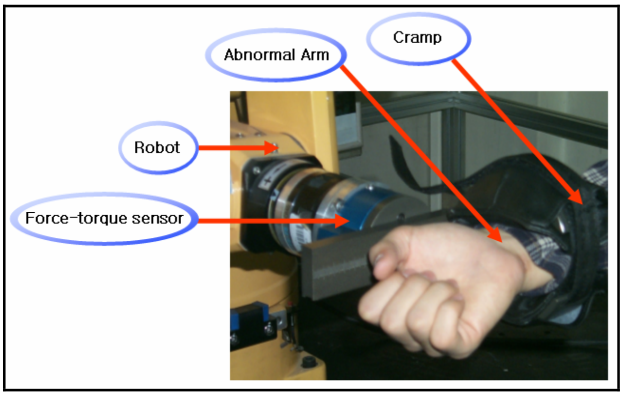
Abstract: This study proposes an industrial rehabilitation robot system which can exercise two joints in 3 dimensional spaces. The robot kinematics analysis and the results of studies on each joint for the rehabilitation robot could verify possibility of rehabilitation motion to exercise a joint. The force and torques sensor not only measures a rehabilitation performance of subjects between the abnormal limb and the manipulator, but also carries out an important function of safety device to prevent accidents. Also, limit sensors and emergency stop switch are used for high safety in this system. In this real test, the possibility of rehabilitation robot system is evaluated by C&R ARM Ⅰ which is similar to upper-limb.

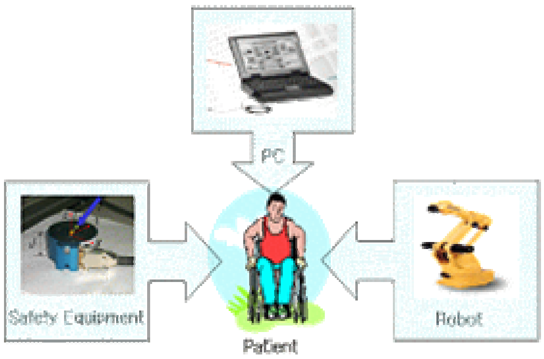
Key Words : Industrial rehabilitation robot system, Force and torques sensor, Emergency stop switch, C&R ARM Ⅰ

1. INTRODUCTION

According to the popularization of high speed transport and an aging society, accidents and orthopedic problems are increasing. These patients who were caused by accidents and orthopedic problems need rehabilitation therapies for normal life. Hence not only therapists but also rehabilitation devices are employed for the patients. Recently, the rehabilitation therapy is supported by various kinds of systems. However, these devices can give only 1 or 2 degree-of-freedom motion for one joint. However, when the paretic subjects are receiving treatment for their two or three joints, they need to change the rehabilitation devices or connection device between robot and subject's limb for his joints. Therefore, it demands time for treatment. This study proposes an industrial robot system which can exercise two joints in 3 dimensional spaces at the same time for rehabilitation. The proposed robot system is consisted with rehabilitation robot, seat part that is help to subjects for rehabilitation, connection device between robot and subject's limb and safety devices which prevent a disoperation of robot during the rehabilitation.



(a)



(b)

Fig. (a) Real appearance (b) System component

2. METHOD

To judge the possibility for rehabilitation using a robot, we simulate not only a rehabilitation motion with the kinematics analysis of robot and the result of kinematics' study about human body, but also a rehabilitation motion that exercise two joint at the same time. Also, to real experiment, the force/torque sensor is equipped to the robot's end-effector and we not only evaluate the recovery effect, but also improve the safety. However, it is dangerous to carry out experiments with human under the present conditions and it is difficult to gain the objective data. As it turned out, we carry out experiments with C&R arm Ⅰ that is similar to human's upper-limb.

2.1 Motion trajectory simulation

The rehabilitation with an industrial robot means that the robot system takes the place of the existing rehabilitation devices.

As it turned out, the robot system carries out not only 1 degree-of-freedom rehabilitation motion as the same existing devices, but also multi-degree-of-freedom rehabilitation motion that the existing devices can't perform. Therefore, in the case of using an industrial 6 DOF robot, the various simulations of rehabilitation motion were performed to know the possibility of rehabilitation system. We select the several rehabilitation motions that are shown in Table 1 and can carry out the existing rehabilitation device for simulation. Also we select the motion ranges for this rehabilitation motions. The mean values of joint range are selected from the motion range in the table 1.

Table 1 Range of Rehabilitation motion

Joint	Motion	Range(degree)
Shoulder	Flexion/Extension	-50 ~ 180
	Abduction/Adduction	0 ~ 180
Elbow	Flexion/Extension	-5 ~ 145
Hip	Flexion/Extension	-15 ~ 125
	Abduction/Adduction	-20 ~ 45
Knee	Flexion/Extension	0 ~ 130

As the motion range of table 1 indicates, we obtained the simulation results about the rehabilitation trajectories using an industrial robot through the kinematics analysis of robot and human body. The selected subject tall is 175㎝ and it base the information about length of limb on S. J. Park's paper.

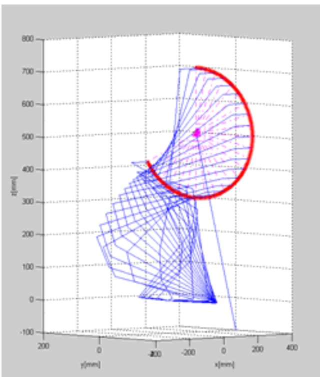


Fig. 2 Shoulder Flexion/Extension(1 joint)

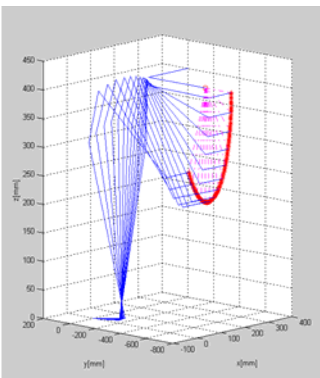


Fig. 3 Elbow Flexion/Extension(1 joint)

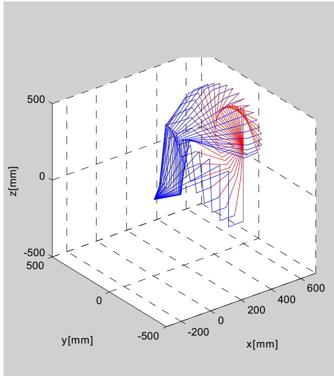


Fig. 4 Shoulder E/F-Elbow E/F(2 joint)

The Fig. 2, Fig. 3 and Fig. 4 show us that the blue lines are robot trajectories and the red lines are limb trajectories. As the figures indicate, exactly, the end-effector of robot keeps up with the end of limb's trajectories during the rehabilitation motion.

2.2 Experiment

Force-torque sensor, limit sensors and emergency switch are used for safety in this robot system. In this system, force-torque sensor is at the end of robot and evaluates an emergency situation with force between subject and robot. Limit sensors evaluate the operation range of robot and robot is stopped at the dangerous zone. Also If the subject push the emergency switch, the emergency switch would use to prevent accidents that can be occurred from robot to human. The force-torque sensor that can get the six-axis information in this system can be the data of F_x, F_y, F_z and M_x, M_y, M_z. The figure 5 shows a Cartesian coordinate of force-torque sensor.

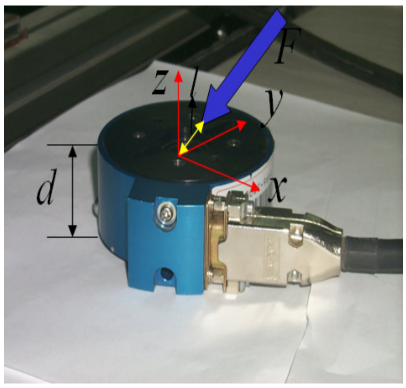


Fig. 5 Force-Torque Sensor Cartesian Coordinates

When the subject who has abnormal upper-limb receives the physical therapy, we are needed to safety problem. Therefore the reflective force of subject is measured with force-torque sensor and if this force is higher than a selected force or moment, robot is stopped automatically. When an arbitrary force is loaded to force-torque sensor, if the angles between X, Y, Z axis and force should be α, β , γ , the force elements and moment elements of X, Y, Z axis can obtain, as

$$F_x = F\cos\alpha \quad (1)$$

$$F_y = F\cos\beta \quad (2)$$

$$F_z = F\cos\gamma \quad (3)$$

$$M_x = F_y \times d + F_z \times l_y \quad (4)$$

$$M_y = F_x \times d + F_z \times l_x \quad (5)$$

$$M_z = F_x \times l_y + F_y \times l_x \quad (6)$$

where, l : the shortest distance between the origin and the force position.

d : the length of force-torque sensor.

However, it is dangerous to carry out experiments with human under the present conditions and it is difficult to gain the objective data. As it turned out, we carry out experiments with C&R arm Ⅰ that is similar to human's upper-limb. C&R arm Ⅰ is made how it can operate the 3 DOF at the shoulder and 1 DOF at elbow, similar to human's upper-limb. And it can measure the rotation angle with encoders of each joint.

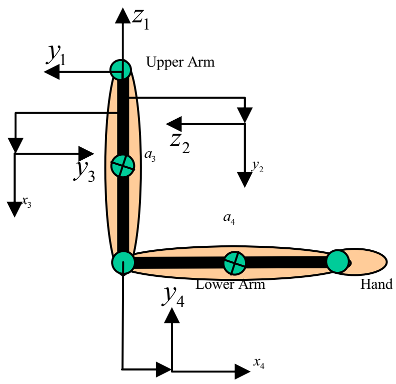


Fig. 6 Experiment mechanism (C&R arm Ⅰ) Coordinates

Table 2 D-H table of C&R arm Ⅰ

	α_{i-1}	a_{i-1}	d_i	θ_i
1	0°	0	0	θ_1
2	-90°	0	0	θ_2
3	-90°	0	0	θ_3
4	0°	a_3	0	θ_4

Fig. 5 C&R ARM Ⅰ

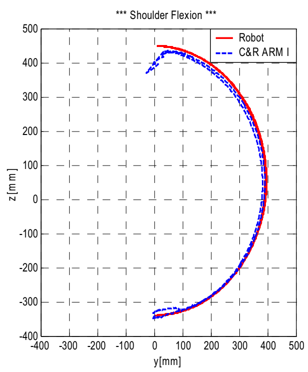


Fig. 6 Shoulder Flexion

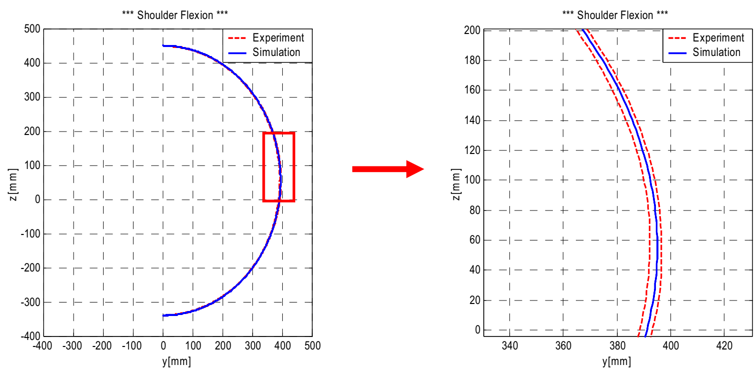


Fig. 7 Shoulder Flexion (Comparison of Experiment & Simulation)

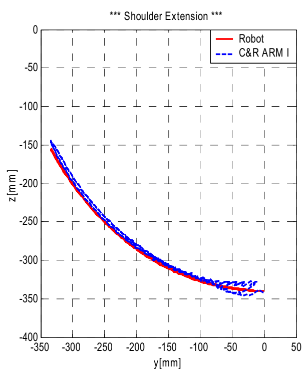


Fig. 8 Shoulder Extension

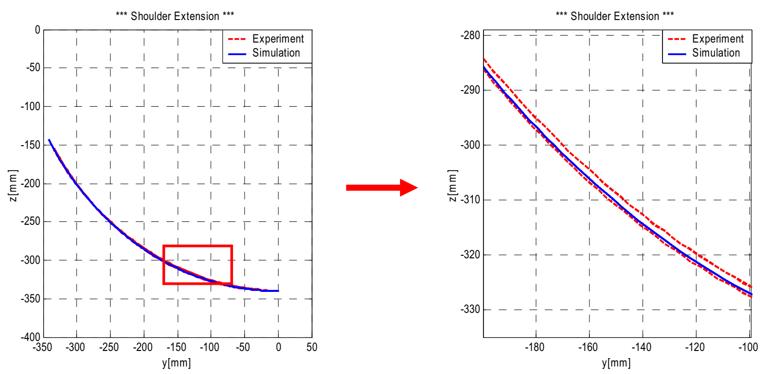


Fig. 9 Shoulder Extension (Comparison of Experiment & Simulation)

3. RESULT

The results of experiment not only compared experiment's data with simulations but also compared the trajectory of robot end-effector with the trajectory of C&R arm I(Fig. 6 and Fig. 8). The simulation results present that proposed robot system can perform rehabilitation motions, sufficiently. Also, the resulting motions show the same tendency in the experiment for shoulder extension/flexion. And errors are found in a general motion range. However, the experiment results present many errors in the edge of motion trajectory. These errors occurred between robot and C&R arm I. The following results are what experiment the trajectories with motion range of arm. When we confirm the results of experiment and simulations through the total motion range of robot, we show little error(Fig. 7 and Fig. 9). Therefore, we magnify the large error part and we can find the biggest 3mm error from shoulder Flexion and Extension. These errors are appeared from the fixing of initial position and the convergent velocity of each joint.

4. CONCLUSION

As the results of simulation and experiment, the trajectories of robot motion are similar to those of C&R arm I. Therefore we can verify the possibility of robot rehabilitation system. In future work, the factor of errors has to be eliminated and a new device which connects robot and body has to be developed for accuracy. Also, a lot of safety devices are demanded to the experiment with human

5. ACKNOWLEDGEMENTS

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