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A Feasibility Study on a Robotic Exercise System for MDOF Physical Rehabilitation Therapy

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This paper presents a robot system developed for medical purpose. A 6-degree-of-freedom robot was introduced for physical exercise and rehabilitation. This system was proposed for stroke patients or patients who cannot use one of their arms or legs. The robot system exercises the hemiplegic part based on the motion of normal part of a patient. Kinematic studies on the human body and robot were applied to develop the robotic rehabilitation exercise system. A clamp which acts as an end effector of the robot to hold a patient was designed and applied to the robot to guarantee the safety of patients. The proposed robotic rehabilitation system was verified by simulations and experiments on arm (elbow and shoulder) motion. Patients are expected to be able to exercise various motions by themselves with the proposed robotic rehabilitation system.

Key Words : Rehabilitation Therapy, Physical Exercise, Medical Robot, Symmetry Operator

Nomenclature

$^{H}R_{N.P}$ 3×3 rotation matrix of the normal part frame with respect to the human frame
$^{H}P_{N.P}$ 3×1 position vector of the origin of normal part frame in the human frame
$^{H}X_{A.P}$ 4×4 matrix containing orientation and position of abnormal part in human body
$^{H}X_{N.P}$ 4×4 matrix containing orientation and position of normal part in human body
$^{C}T_{H}$ 4×4 transform matrix from the human frame into the chair frame
$^{R}R_{C}$ 4×4 transform matrix from the chair frame into the robot frame

1. Introduction

Recently, robot technology has rapidly changed the ways of medical care. There have been many kinds of medical robots and related technique such as endoscope robots (Lin Liangming et al., 1997; Vara-Thorbeck et al., 2001); operation and operation assistant robots (Lavallee et al., 1991; Casals et al., 1996); physical exercise robots (CPMs) and assistant robots for the physically handicapped (Colle et al., 2002); and measuring (Sehyun Shin et al., 2002) and operation (Duk Sun Yun et al., 2002) technique. The applications of robots in medical and service fields are increasing rapidly.

This paper introduces a kind of medical robot system providing physical exercise for rehabilitation. In the case of stroke, efficient and system-

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atic rehabilitation therapy is important after the treatments for acute symptoms (Sivenius et al., 1985). The damages in bones, joints, and muscles are treated by surgery and medicine up to a certain extent, physical therapy nevertheless is needed to recover their normal condition (McCann et al., 1993). The physical therapy helps the rehabilitation : increasing the range of motion (ROM) and strengthening the muscles by exercise and training. Passive motion in the ROM and stretching are prescribed to increase the ROM (Esselman et al., 1994). To improve the muscular strength, isometric, isotonic, and isokinetic exercises are recommended. Patients can do isometric and isotonic exercise by themselves relatively easily with simple equipment and various loads. Passive motion needs some kinds of CPM machines or physical therapists. The isokinetic exercise is a special type and needs a special machine that can control the velocity and force of motion simultaneously. As well as exercise, measuring the velocity and force is an important function of isokinetic exercise machines (Kellis et al., 1995 ; Bentley et al., 2000).

The exercise for rehabilitation is applied to one joint at one time in a conventional way. Most equipment and exercise machine are developed for one joint motion. Most CPMs are dedicated to a specific joint. Therefore, as many kinds of CPMs as the number of joints are needed to satisfy various kinds of human motions. The isokinetic machines (KIN-COM, Cybex, etc.) can be applied to various joints, but the configuration of the machine should be reconfigured depending on the corresponding joint.

In this paper, a robot system for physical exercise is introduced. This robot system was studied to generate passive and isometric motions and to apply these motions to 2 joints simultaneously (e.g. shoulder and elbow). The proposed robot system can be applied to various joints and replace various kinds of physical exercise devices. The kinematics of human extremities and the robot are studied to setup the robotic exercise system. The motions for rehabilitation are captured from the normal part of a patient and replayed by the robot to exercise the abnormal part. The reaction forces during exercise are measured to control the robot system and to guarantee safe exercise.

The physical exercises are studied in sec. 2. These results are applied to the design of the control scheme for the robotic rehabilitation exercise system. The modeling of the robot and human extremities are analyzed to derive a method to generate exercise motion in sec. 3. In sec. 4, the system components are presented. This section presents configuration of the system with major system components and their functions. The experiments and the results are shown and discussed in sec. 5 to verify the proposed system. Section 6 concludes.

2. Rehabilitation Exercises and Control Scheme

In this section, the physical exercises for rehabilitation are studied. The physical exercises are explained briefly and with the result the control schemes for the robotic rehabilitation system are derived.

The physical exercises for rehabilitation therapy can be classified into active and passive motions. Patients should move their extremities by themselves in active motion. The active exercise system provides patients with loads or resistance for exercise and measures the results. The active exercises are divided again into isometric, isotonic, and isokinetic motions. In passive motion, patients are exercised passively by the exercise system. Among these four types of exercises, the isometric and passive motions are targeted to be realized into the robotic rehabilitation exercise system.

2.1 Isometric exercise

Literally, isometric means equal length. When a muscle contracts without any appreciable change in length this is referred to as isometric contraction. A muscle contracts but cannot be said to be acting either concentrically or eccentrically.

Hislop and Perrine (1967) described isometric exercise as muscular contractions against a load which is fixed or immovable or is simply too much to overcome. One six second isometric contraction at two-thirds maximum performed once each day for five days was sufficient for 5% strength gain per week (Muller et al., 1954). This received a disproportionate amount of publicity from which it would appear that the medical community has never recovered.

Although it has been shown that strength gain is possible from isometric contraction this strength gain is very minimal and almost all studies since have shown that the gain in pure muscular strength is only at the specific angle at which the exercise is performed. Hence, to make isometric exercise effective at increasing functional strength it must be repeated at many different joint angles. Isometric improvements have also been shown to be rate specific (Morrissey et al., 1995) this means that isometric strength gain can be best utilized only at particular speeds.

For those who have suffered muscular or tendons injuries the consequences can be dire. Isometric exercises are, however, extremely good for strengthening muscle groups around an injured joint as the joint surfaces actually distract from one another during isometric contraction. However, following isometric exercise there is a decrease of muscle power by up to 60-70% (Tidas et al., 1995) this can last for up to 96hrs (4 days). During this time the associated joints are exposed to much higher than normal impact and sheer forces as they have lost one of their most vital protective mechanisms. This could lead to discomfort as demonstrated by Melchionda et al. (1984) which is not experienced with isokinetic concentric contractions (Dvir, 1995).

2.2 Continuous passive motion (CPM)

Continuous Passive Motion is a postoperative treatment method that is designed to aid recovery after joint surgery. In most patients after extensive joint surgery, attempts at joint motion cause pain and as a result, the patient fails to move the joint. This allows the tissue around the joint to become stiff and for scar tissue to form resulting in a joint which has limited range of motion and often may take months of physical therapy to recovery that motion.

By using a motorized device to move the joint very gradually, it is possible to significantly accelerate recovery time by decreasing soft tissue stiffness ; increasing range of motion ; promoting healing of joint surfaces and soft tissue ; and preventing the development of motion-limiting adhesions (scar tissue) (Johnson and Eastwood, 1992). Interestingly, this is accomplished without patient effort (passively) as the machine moves a joint through a prescribed range of motion for an extended period of time. Studies have shown that patients using CPM devices require less pain medication then patients who have had the same type of surgery and are not using this device (Chen et al., 2000).

2.3 Control schemes

The control schemes for the robotic exercise system are summarized in Fig. 1. The control schemes were designed to realize the characteristics of the exercises explained previously. The flowchart (a) in Fig. 1 describes CPM exercise. The control flows from the marker ⓐ to ⓑ for CPM exercise. As shown in the flowchart (a) the exercise motion is given to the robot as a series of positions. The reaction force and torque are measured to check the safety of patient. If measured force (F) is greater than the preset level (F_{safe}), the robot moves backward to its previous position to relieve the reaction force in human arm. In safe condition ($F < F_{safe}$), the robot is

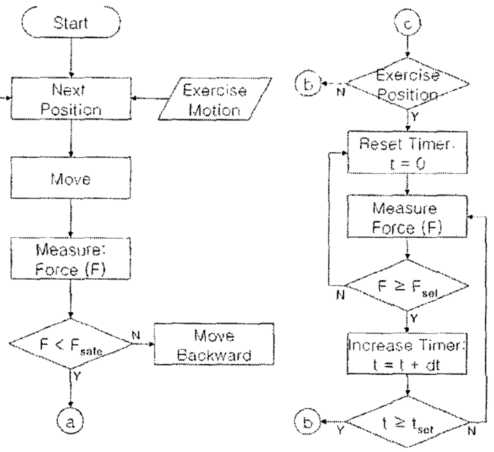


Fig. 1 Control scheme of the robotic exercise system

controlled to proceed next position.

As explained above, isometric exercise must be repeated at many different joint angles. The flowchart (b) in Fig. 1 shows the control for isometric exercise at one joint angle. The control flows from the marker ⓐ to ⓒ to repeat isometric exercise at different joint angles along the CPM motion. For isometric exercise, three parameters : interval in position, force level (F_{set}), and duration (t_{set}) are given. When the robot reaches at the isometric exercise position, the robot is controlled to stop and wait the patient to apply prescribed force (F_{set}) for prescribed duration (t_{set}). These parameters (F_{safe}, F_{set}, and t_{set}) are inputs to the control program of the system.

Therefore, the robotic exercise system basically realizes CPM exercise. During both mode (isometric and CPM), the robot replays the exercise motion generated from normal motion of a patient.

3. Exercise Motion Generation

The basic idea of generating exercise motion is that the robot exercises the abnormal part of a patient following the motion obtained from the normal part of the same patient. With this idea the exercise motion can be generated easily without specifying the details of the motion. Figure 2 illustrates relations between the robot and a patient. The kinematics of the robot and human extremities are analyzed to find the transformations in Fig. 2.

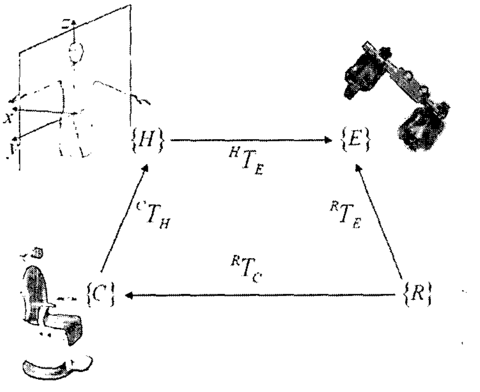


Fig. 2 Relations between the robot and patient

3.1 Kinematics of the robot and human extremities

A robot, "FARA AS2" from Samsung Electronics was introduced as the exercise robot. The robot is an industrial vertical multi-joint type with 6 DOF. Figure 3 shows FARA AS2 and coordinate frames. The mechanism of the robot is defined with Denavit-Hartenberg (DH) notation as shown in Table 1.

The human extremities are modeled as 4 DOF : 1 DOF at elbow joint and 3 DOF at shoulder joint for an arm, and 1 DOF at knee joint and 3 DOF at hip joint for a leg. The shoulder and hip joints are modeled as a combination of 3 revolute joints and the centers of revolutions are assumed to be coincident (Kumar et al., 1995), (Norton and Kohles, 2001). Figures 4, a and b show the

Table 1 DH parameters for the FARA AS2

i	α_{i-1} (degrees)	a_{i-1} (mm)	d_i (mm)	α_{i-1} (degrees)
1	0	0	0	θ_1
2	−90	150	0	θ_2
3	0	350	0	θ_3
4	−90	100	350	θ_4
5	90	0	0	θ_5
6	−90	0	95	θ_6

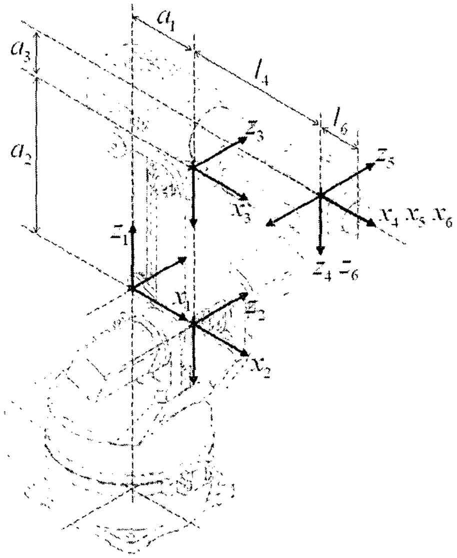
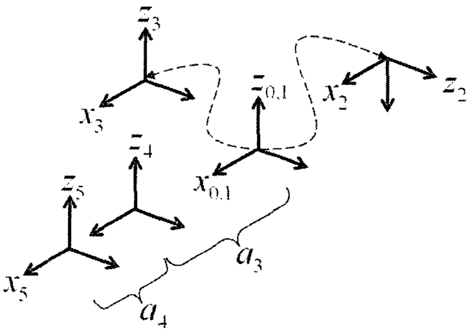


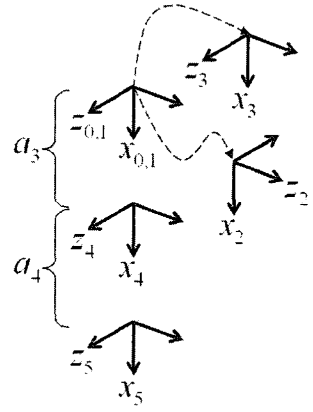
Fig. 3 FARA AS2 - a 6 DOF industrial robot

Table 2 DH parameters for human extremities

i	α_{i-1} (degrees)	a_{i-1} (mm)	d_i (mm)	α_{i-1} (degrees)
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



(a) Arm

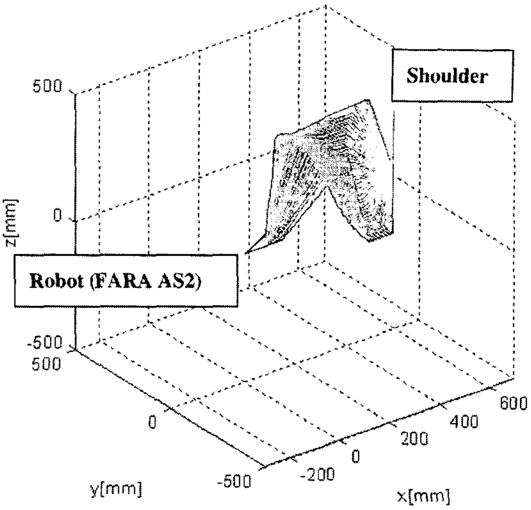


(b) Leg

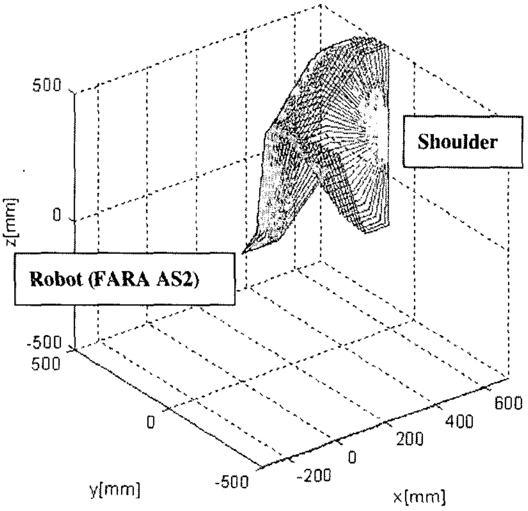
Fig. 4 Modeling of a human extremities

oordinate frame of an arm (Fig. 4(a)) and of a leg (Fig. 4(b)). The DH table is shown in Table 2. The DH parameters of arms and legs are the same because the human extremities are modeled in the same way. The variable a_3, in the Table 2, is the length of the upper part of human extremity.

The coupled motion of human and robot was studied based on the result of each study. When the robot exercises human extremities, the end effector of the robot holds the lower part of arm or leg so rigidly that the relative position and orientation between human extremities and robot are unchanged. Though this assumed rigidity is impaired by the soft tissue of human body and the cushions surrounding robot end effector, many physical exercise machines use practical fixation rigid enough to realize exercise motion.



(a) Elbow flexion



(b) Shoulder flexion

Fig. 5 Simulation of human — robot coupled motion

The coupled motion is simulated with the assumption that the robot holds human extremities rigidly. Figure 5 shows simulations for shoulder flexion (Fig. 5(a)) and elbow flexion (Fig. 5 (b)). These simulations show the validity of the kinematics studies for human arm and robot.

The dynamic properties of robot and human extremities are of little concern because the physical exercise motion is not considerably fast.

3.2 Generation of the exercise motion

The path for exercise motion is generated on the assumption that human body is symmetric with respect to the plane containing spine. This plane is shown as Y-Z plane in Fig. 2.

With a motion capture device, the motion of normal part of a patient, ${}^{H}X_{N.P}$ is obtained as Eq. (1). For simplicity, it is assumed that the motion is captured at the corresponding parts of both arms or legs (e.g. mid point of the lower arm, where the exercise robot holds on).

$$ {}^{H}X_{N.P}=\begin{bmatrix} {}^{H}R_{N.P} & {}^{H}P_{N.P} \\ 0 & 1 \end{bmatrix} \tag{1}$$

${}^{H}X_{N.P}$ is transformed into ${}^{H}X_{A.P}$, the motion of abnormal part of the same patient, utilizing the symmetry of human body.

$$ {}^{H}X_{A.P}=symm({}^{H}X_{N.P}) \tag{2}$$

$symm(\ )$ is an operation for the symmetry with respect to the Y-Z plain in Fig. 2. In case of position, the symmetry transformation with respect to Y-Z plain is given

$$ T_{symm}=\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3}$$

However, if a rotation matrix is transformed with Eq. (3), the consistency of coordinate system is lost. Therefore, a symmetry operation $symm(\ )$ is defined as follows.

$$ X_{left}=symm(X_{right}) \tag{4}$$

Where, $X_{left}=[C_{l1}\ C_{l2}\ C_{l3}\ C_{l4}]$ and $X_{right}=[C_{r1}\ C_{r2}\ C_{r3}\ C_{r4}]$

$$ C_{li}=\begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} C_{ri},\ (\text{for } i=1,\ 3,\text{ and } 4)$$

and

$$ C_{l2}=C_{l3}\times C_{l1}$$

Using the defined symmetry operation, the consistency of coordinates system is maintained.

${}^{H}X_{A.P}$ represents the exercise motion with respect to the patient. To generate the exercise motion with respect to the robot, ${}^{H}X_{A.P}$ should be transformed again with Eq. (5) into the robot frame.

$$ {}^{R}X_{A.p}={}^{R}T_{C}{}^{C}T_{H}{}^{H}X_{A.P} \tag{5}$$

The transformation from human frame to robot frame is separated into 2 transformations, human-to-chair and chair-to-robot, because after the relative position between robot and chair is fixed, the posture of patients can be changed by adjusting head rest or back of the chair.

To generate ${}^{C}T_{H}$ and ${}^{R}T_{C}$, relative position and rotation between the frames of patient and chair ; and chair and robot are required.

The dimensions of patients, relative positions between major components must be measured. The dimensions and the ROM of patient are grouped into the patient parameter. With these parameters, ${}^{H}T_{E}$ is found, and the range of exercise motion is limited. The position parameters are the relative positions and rotation between patient and chair ; and chair and robot. The transformations ${}^{C}T_{H}$ and ${}^{R}T_{C}$ are comprised of these parameters. Lastly, the robot parameters are the dimensions robot and are contained in ${}^{R}T_{E}$.

4. System Components

The robotic exercise system was designed to realize the exercise motion as stated previous

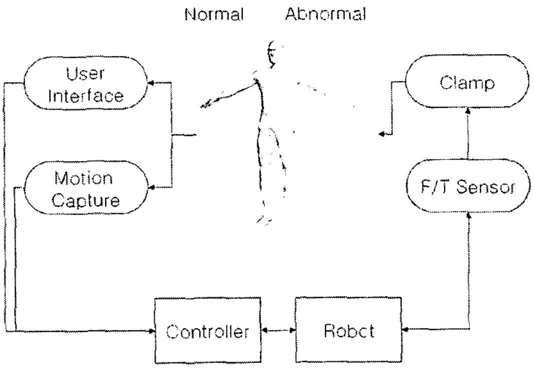


Fig. 6 Components and organization of the robotic exercise system

section. Followings are studies and considerations on designing of the robotic exercise system. The components and their connections of the system are shown in Fig. 6. The details of components and control program are stated in this section.

4.1 Robot and clamp

The work space and payload are important specifications for the robot system in this study. The specifications on precision, velocity, and acceleration of most industrial robot systems surpass the required level for a rehabilitation exercise robot. However, the payload becomes very important specification for a rehabilitation exercise robot. During the passive motion, the force and/or torque capacity of the robot must be limited, but during the active motion, the robot should provide enough load or resistance to patients.

The connection between robot and human extremities is made by a clamp. It is an indispensable component for the robotic exercise system, because it is used as an end effector for the exercise robot. The clamp holds human extremities to prevent relative motion between robot and human extremities. The clamp must be designed to meet two conflicting goals: secure hold and safety-guarantee. Precise exercise needs tight hold however, the hold must be released over excessive forces or torques for the safety of patients.

The safety is very important for the robot and the clamp. Because the robot exercise patient in direct contact, the robot system must be equipped with safety devices such as emergency stop and maximum speed / acceleration limit. The clamp can be designed to include the emergency stop.

4.2 Force and torque sensor

An F/T sensor placed at the end effector measures reaction force and torque during exercise. The force-torque information is utilized in two ways. One is securing safe exercise and the other is estimating the rehabilitation process. If forces or torques in opposing direction of motion exceed a prescribed level, the robot stops for safety. Because these kinds of reactions happen when the limits of the ROM of the paralyzed part are reached, the robot must stop exercise and relax the arm or leg. Besides the safety purpose, the force-torque information can give the estimation for the rehabilitation process. The force-torque elements measured during the exercise show how well the rehabilitation exercise progresses (Lum et al., 1999).

Because the coordinate frame of F/T sensor is changed depending on the orientation of the end effector, the force-torque information should be transformed into the reference frame of the robot, however. For the transformation, the results of studies on kinematics in sec. 3 are applied.

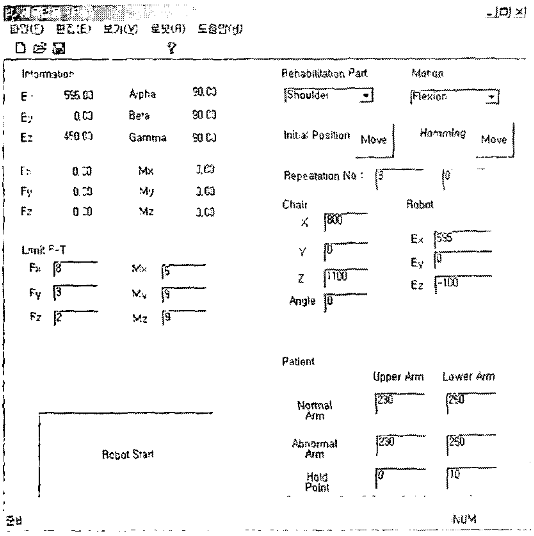
4.3 Motion capture device

There are many possible devices to capture the motion of human extremities. As in the case of exercise robot, explained before, the motion capture device also have as large work space as human extremities. An exoskeleton type (Cha et al., 1998) or a wire type (Sim et al., 1998) master robots are preferred because of their large work space. An exoskeleton type device can have almost the same work space as human extremities. However, the complexity and the weight of the device can be burden to patients. A wire type device also has large work space and it is easy to use for patients, but the volume of the device must be large enough to contain the work space of patients.

Once the exercise motion is captured, this motion is recorded and processed to be applied to the abnormal part. A master-slave scheme can be applied to the robotic exercise system besides the record-and-replay scheme. The motion from normal part of a patient drives the exercise robot directly without recording the motion. Patients can control the robot with a master device to exercise abnormal part themselves. They can control the exercise load or ROM feeling their own abnormal part.

4.4 Control program

The main function of the control program is generation of the exercise motion. The control program has following functions: capture of



Information
Ex 555.00 Alpha 90.00
Ey 0.00 Beta 90.00
Ez 450.00 Gamma 90.00
Fx 0.00 Mx 0.00
Fy 0.00 My 0.00
Fz 0.00 Mz 0.00

Limit F-T
Fx 8 Mx 5
Fy 3 My 9
Fz 2 Mz 9

Rehabilitation Part: Shoulder
Motion: Flexion
Initial Position
Homming
Repeatation No : 3 0

Chair
X 800
Y 0
Z 1100
Angle 0

Robot
Ex 555
Ey 0
Ez -100

Patient

	Upper Arm	Lower Arm
Normal Arm	230	250
Abnormal Arm	230	250
Hold Point	0	10

Fig. 7 Screen shot of the control program

normal motion ; generation of exercise motion ; and control of the robot. For these functions, the parameters introduce in sec. 3 are required. Because the robot parameters can be embedded in the control program, generally, it is unnecessary to measure the dimension of the robot repetitively. However, the patient parameters and position parameters must be measured case by case and these parameters are used for the control program as inputs. The studies on the body segment (Pearsall and Reid, 1994) can simplify the process of measuring human body. With this method, the lengths of body segments are given as ratios of height or obtained from video data instead of direct measuring. However, these methods have limits in accuracy. Figure 7 shows a user interface window of the control program.

5. Experiments

For the experiments, a 6 DOF industrial robot (FARA AS2) as the exercise robot and a PC mouse as the motion capture device were introduced and the clamp and control program was designed. The experiment system was controlled by a PC with a motion controller. Figure 8 shows the experiment system.

A dummy arm, called 'C&R Arm II' was designed for experimental purpose. Experiments with human subjects are dangerous and quantitative data cannot be acquired. The C&R Arm II is a 2-link mechanism used as a substitute for human arms. The robot exercises the C&R Arm II instead of a real human arm in experiments. The C&R Arm II has 4 DOF (1 DOF at elbow and 3 DOF at shoulder). All joints of the C&R Arm II are equipped with encoders measuring the angular displacements. The lengths of each link are variable in range of 250~350 mm. With the C&R Arm II, the experiments can be performed safely and the motion of the robot can be measured externally. The C&R Arm II are shown in Fig. 8.

Fig. 8 System setup for experiments

A PC mouse was used as a motion capture device and experiments are performed for planar motions because a PC mouse can capture planar motions and it was easy to adapt a PC mouse to the experiment system. The motion of normal part was recorded by drag a PC mouse on a board or a table located on the motion plane.

The exercise motion of the robot system was verified by comparing three trajectories : the exercise motion, the motion of the robot, and the motion of the C&R Arm II .

The motions of the robot and the C&R Arm II are obtained with the joint variables. Because the robot holds the C&R Arm II, they have the same trajectory at the holding point. However, the motions of the robot and the C&R Arm II are not coincident because the holding is not solid for the compliance of soft tissue and the cushions surrounding the clamp. Therefore, the motions of the robot and the C&R Arm II must be compared to verify the robot system.

The patient parameters and position parameters are measured with rules. The C&R Arm II must be adjusted following the patient parameters.

For the experiment, simple motion of upper extremity was introduced to verify the robotic exercise system. Figures 9~13 show the results of the experiments. Each plot contains trajectories of the robot end effector and the C&R Arm II.

The Y-Z plane lays sides of a human body. The origin is located at the shoulder joint. The solid line presents the trajectory measured from the robot joint variables and the trajectory form the C&R Arm II is presented by a perforated line.

The solid lines show smooth trajectories and no abrupt change because the robot is a well-built industrial one. The normal motion and the exercise motion from the robot are identical and these are expected results. The main attention should be paid on the comparison of motions of the robot and the C&R Arm II (solid line and

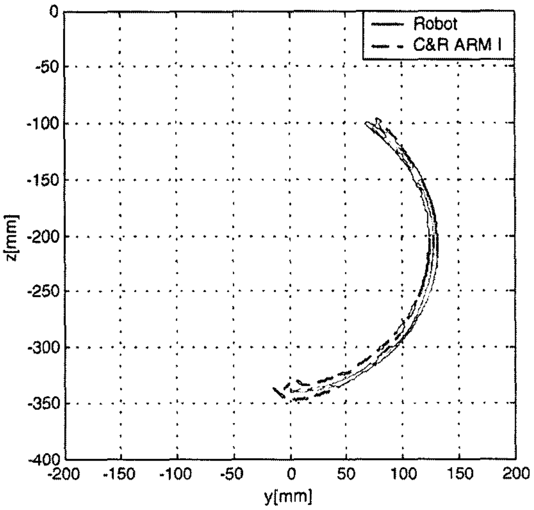


Fig. 9 Elbow flexion

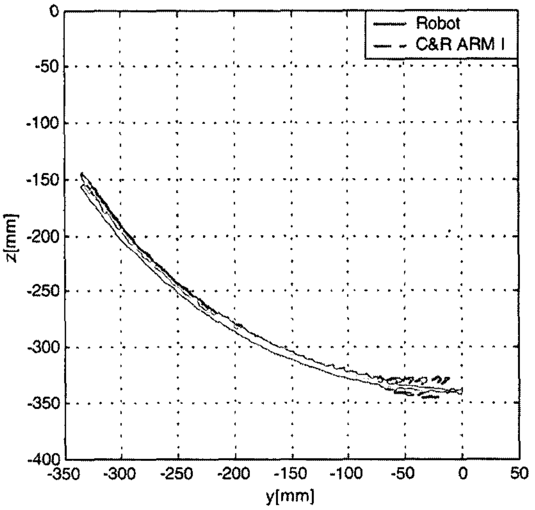


Fig. 11 Shoulder extension

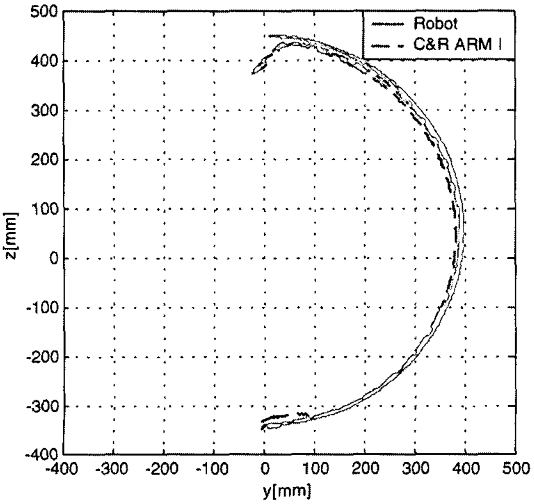


Fig. 10 Shoulder flexion

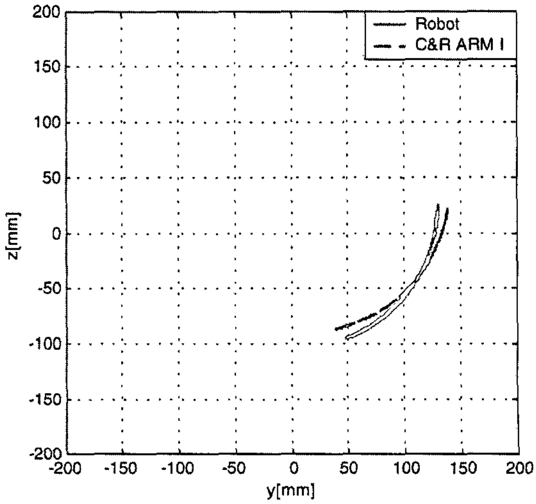


Fig. 12 Shoulder internal rotation

perforated line).

The perforated lines (C&R Arm II) and the solid lines (robot) are almost identical and there are errors in every case. These errors can be explained with following causes. As explained, the C&R Arm II was adjusted with the patient parameters. In the course of the measurement and the adjustment, errors can be accumulated. Another major cause can be found in the connection method. The Compliance and the sliding at the clamp are unavoidable because the contacting part is soft and tight holding is uncomfortable for the patients. These problems are common for every physical exercise machine like CPMs.

The errors are noticeable at both ends of trajectories. These errors can be explained with the slid and the deformation at the clamp. Especially, in Fig. 10 (shoulder flexion), when the shoulder is fully flexed over the head, a relatively large amount of errors were observed because of the slid.

There are different types of errors in Fig. 12 and 13. For the experiment of shoulder internal/external rotation, the elbow of the C&R Arm II was flexed about 90 degrees. This posture of the arm and the error factors mentioned above are combined and the center of rotation is shifted consequently.

Similar type errors of shoulder internal/external rotation are observed when the C&R Arm II and robot are misplaced, however, these errors are larger and vanish when the relative position is correct.

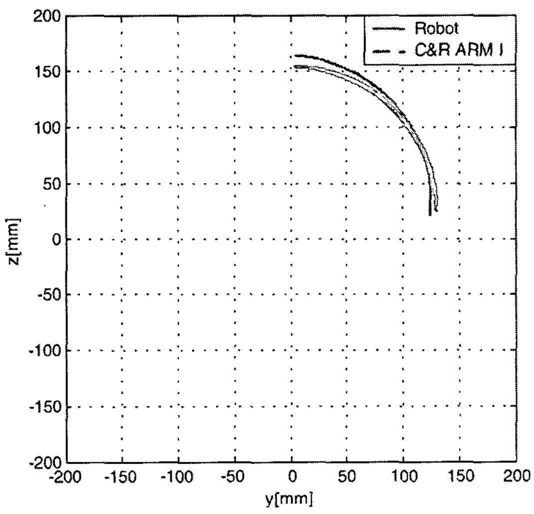


Fig. 13 Shoulder external rotation

6. Conclusion

The robotic exercise system was studied and designed, and the system was verified with CPM motions. The CPM motion is basic exercise motion for active exercises. The main merit of the robotic exercise system is that the system can exercise 2 joints simultaneously by one system.

In this study, a method to generate the exercise motion from the motion of normal parts of a patient was introduced. With this method, the exercise motion can be generated without complicated programming for motion. The symmetry operator was defined through the study of kinematics. The normal motion can be transformed to the exercise motion with the symmetry operator.

The physical exercises are studied to derive control schemes for the exercise robot. Two types of physical exercises: isometric and CPM exercises are studied and the characteristics of exercise motions are realized by the robot. These two types of exercises are the bases of other exercise motions. Therefore, other exercises: isotonic and isokinetic exercises can be realized with the results of this study.

The control program of the robotic exercise system was developed. Exercise motion generation, the characteristics of exercise motions, kinematics of the system, and robot control functions are coded into the control program. The control program was designed to have user interfaces for the input of parameters.

On the base of the feasibility of the robotic exercise system, following subjects need more study. First, a comfort and precise clamping device should be developed. The majority of errors in exercise trajectories are caused by the compliance and sliding at clamp.

Second, a positioning sub-system is required. The relative position between a patient and the robot is important to realize the exercise motion. During the experiments, the relative positions between the robot and the C&R Arm II was set and measured manually. A sub-system which can set the relative position in a systematic way and report the dimension is needed to be studied.

In addition to the proposed system, realizing the isokinetic and isotonic exercises remains for future studies. To incorporate these exercises into the current system, more in-depth studies on force information is required.

The studies in this paper show the feasibility of a multi-degree of freedom robotic exercise system for rehabilitation. After guaranteeing safety for the subjects, clinical demonstration should be performed.

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