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A Robot based Nursing care estimation and controlling patients Arms

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Abstract - The demand for robotics to tackle the problems resulting from the ageing society is increasing. For the safety of a dual-arm transfer robot which can lift and move a care receiver from a bed to a wheelchair or the back, this paper proposes a novel control strategy for motion control. The robot arms and the subject being held by the robot constitute a strong coupling system which is under-actuated and nonlinear. To solve the above problem, we divide the manipulation of the system into posture adjustment of the subject in holding and arm-position adjustment when the arms leave the subject for an instance to avoid friction. The posture adjustment of the subject was realized by using a sliding mode control method, while a neural network was introduced to build the control model and identify the parameters, and impedance control was introduced in arm-position adjustment. The effectiveness of the control strategy was confirmed by numerical simulation.

Index Terms - posture adjustment, arm-position adjustment, sliding mode control, impedance control.

I. INTRODUCTION

With the advent of an aging society, the demand for human interactive robots that can help on-site caregivers in nursing humans, particularly the elderly, is increasing. Among the nursing care tasks, patient transfer, such as lifting and moving a bedridden care receiver from a bed to a wheelchair or the back, is one of the most physically taxing tasks in nursing care service [1]. Many kinds of transfer devices and robots have been proposed and developed [2], but although some of them have been commercialized, they are not widely used in nursing care facilities, homes as well as hospitals. The reasons include the long time required for their use, the difficulty of attaching slings, the risk of dropping, and the mental and physical discomfort of the care receiver. In addition, it was reported that the physical burden of the caregiver is not reduced in many cases by using transfer lifts [3].

A few dual-arm nursing care robots have been developed. For instance, the RIBA robot was designed to conduct transfer tasks and succeeded in transferring a human between a bed and a wheelchair, using human-type arms (Fig. 1). It has sufficient power to lift up a human weighing over 80 kg and soft tactile sensors on its surfaces to detect and recognize the contact with the subject being held [4].

Fig. 1 Transfer motions of RIBA robot

In the case when the system is under-actuated during transfer task, the robot and the subject being held constitute a complex nonlinear system, increasing the risk of the instability. Motion control of the robot arms is a whole-arm manipulation, which uses the entire robot arms to handle the subject without shape or force closure [5]. As an external force, gravity was treated as a virtual actuating force [6]. Although the modeling of gravity increases the difficulty of the trajectory planning, it can effectively increase the dimension of the workspace [7].

Many researchers have shown strong interests in wholearm manipulation, especially in the field of nonprehensile manipulation. For example, a single-DOF planar drop robot developed by Mori [8] controlled the translation velocity, angular velocity and direction of the ball using a whole-arm manipulation strategy. Dafle in his article [9] introduced an external driver to model gravity, external contact force, as well as dynamic arm movement to realize the dexterous action of a manipulator. Yamawaki et al [10] conducted a trajectory planning research and built a control strategy for sliding a polygon object by using stochastic programming. Batz et al [11] used a 6-axis industrial robot to capture a sphere by using trajectory prediction and contact point selection.

However, the above researches cannot meet the requirements for dynamic operation of the subject being held, who can be modeled by a multi-link object. Onishi [12] pointed the requirements, conditions as well as difficulties of the operation of a multi-link object. Zyada et al [13]-[16] introduced a multi-link rigid model manipulated by two cooperative manipulators. However, although researches on dual-arm operation have been carried out, no research has been reported on the prevention of friction between the subject and the robot.

The static and dynamic friction of the contact surface plays a pivotal role in the stable operation of a large object using robot arms. One of the main obstacles is the difficulty of mathematical modelling of the complex frictional effects in the manipulation. However, friction must be prevented since it may hurt the skin of the subject. To solve this problem, this paper proposes a novel control strategy. Firstly, the manipulation is divided into hold state and release state, i.e. the posture adjustment of the subject in holding and the arm-position adjustment when the arms leave the subject for an instance to avoid friction. Control law is switched according to the states. In the hold state, the approximate term of a neural network adaptive control law approximation model was designed to achieve a precise control, while in the release state, an impedance controller has been designed to ensure the comfort of the subject.

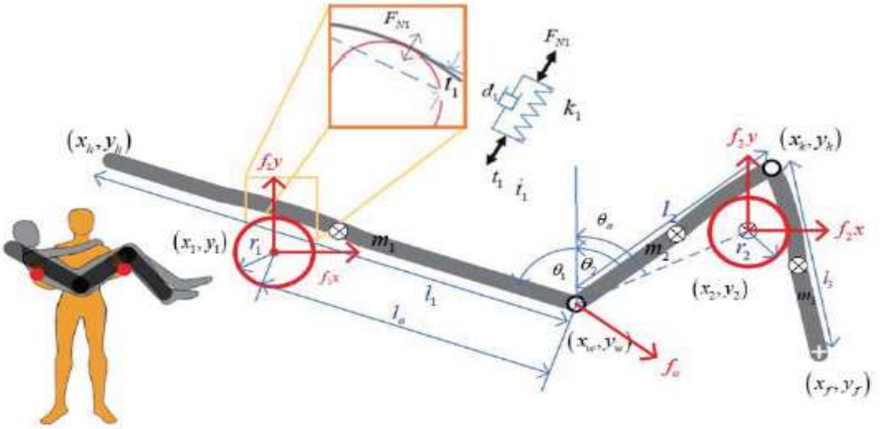


Fig. 2 Schematic diagram of the system

II. SYSTEM DESCRIPTION

To simplify the discussion, we assume that: 1) The robot arms A_j (j = 1,2) are driven only by vertical and horizontal forces, without rotation. 2) The pose of the object can be identified by the magnitudes and directions of contact forces which are detected by tactile sensors on robot arms. 3) The robot arms are rigid, while the object is flexible. 4) There is no sliding due to high friction between the object and the robot arms. 5) The motions of the object and robot arms are in-plane motions in x and y directions.

The schematic diagram of the system is shown in Fig. 2. The object is simplified by a three-link model L_j (i = 1,2,3) with passive joints. The masses, inertia, and length of the links are expressed by m_i,j_i,l_i the position of the extreme point of links is (x_h,y_h), (x_w,y_w), (x_k,y_k), (x_f,y_f). The angle from the positive y-axis of link 1 and link 2 are θ_1, θ_2. The force between L_1, and L_2 is f_α, the deformation of link i is t_i, l_α is the relative position.

The links that model the subject are manipulated by the robot arms which have masses $m_{j\alpha}$ and radius r_j. (x_j,y_j). The driving force of the arms is (f_{jx},f_{jy}). To build a reliable approximate dynamic model, the following assumptions are made: 1) The centroid of link 2 and link 3 as the same as arm 2. 2) The angle from the positive y-axis of arm 2 as same as L_2 3) There are no centrifugal and Coriolis forces. 4) The links are rigid.

The static equation of the system is $G_{eq}(x) = Ʈ_{eq}$, can be expressed as

$$\begin{cases} f_1^{hl}y + f_2^{hl}y = (m_1+m_2+m_3)g \\ f_1^{hl}x = -f_2^{hl}x \\ m_1 g(l_a - l_1)\sin(\theta_1) = T_2 - T_1 \\ m_1 g(l_2\sin(\theta_2) + l_a\sin(\theta_1)) = T_3 + T_4 \end{cases}, \qquad (1)$$

Where

$$\begin{cases} T_1 = (m_2 g + m_3 g - f_2^{hl}y)(l_a\sin(\theta_1) + l_2\sin(\theta_2)) \\ T_2 = f_2^{hl}x((l_2)\cos(\theta_2) - l_a\cos(\theta_1)) \\ T_3 = f_1^{hl}y(l_2\sin(\theta_2) + l_a\sin(\theta_1)) \\ T_4 = f_1^{hl}x((l_2)\cos(\theta_2) - l_a\cos(\theta_1)) \end{cases}. \qquad (2)$$

G_{eq} (x) can be obtained by (1) and (2)

$$\mathbf{G}_{eq}(\mathbf{x})=\left[f_1^{hl}x, m_1^a g+f_1^{hl}y, f_2^{hl}x, m_2^a g+f_2^{hl}y\right]^{\mathrm{T}}. \qquad (3)$$

The dynamic equilibrium can be expressed as

$$\begin{cases}(f_1^{ml}y\sin(\theta_1)+f_1^{ml}x\cos(\theta_1))l_3=T_a\\ T_a=-f_a\cos(\theta_1+\theta_2-pi/2)l_1\\ f_1^{ml}y=m_1\ddot{y}+f_a\cos(\theta_2)\\ f_1^{ml}x=f_a\sin(\theta_2)+m_1\ddot{x}\\ f_2^{ml}y=(m_2+m_3)\ddot{y}-f_a\cos(\theta_2)\\ f_2^{ml}x=-f_a\sin(\theta_2)+(m_2+m_3)\ddot{x}\end{cases} . \qquad (4)$$

M_{eq} (x) Xis given by

$$\mathbf{M}_{eq}(\mathbf{x})\ddot{\mathbf{x}}=\left[f_1^{ml}x,\ f_1^{ml}y+m_1^a\ddot{y},\ f_2^{ml}x,\ f_2^{ml}y+m_2^a\ddot{y}\right]. \qquad (5)$$

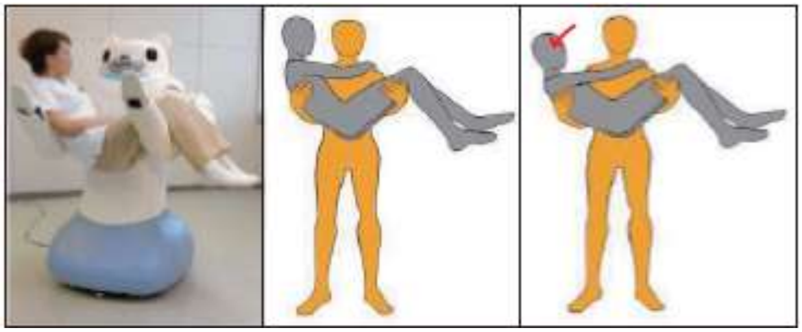


Fig. 3 Schematic diagram of subject posture adjustment

III. ADAPTIVE SLIDING MODE CONTROLLER

A. Control targets

As shown in Fig. 3, the control target is to make the robot mimic the movements of humans when they are holding people under the guidance of the control system.

Model-based control law requires greater switching gain to compensate model errors [17]. To reduce the switching gain and weaken the chatter of the system [18], a neural network control strategy for the system with unknown parameters is presented. The generalization and the robust property of the neural network have been confirmed in many fields [19], which can implement approximating nonlinear functions with arbitrary accuracy by regulating variable weight connection [20].

B. System state variables and ideal dynamics model

The input is $\boldsymbol{\tau}=[f_{1x}, f_{1y}, f_{2x}, f_{2y}]^{\mathrm{T}}$. Take position and velocity of robot arm 1 as the coordinate origin and the subject position is $\mathbf{x}=[x_1, y_1, x_2, y_2]^{\mathrm{T}}$, dynamics model can be transformed into

$$\mathbf{M}^*(\mathbf{x},\mathbf{Q}_t)\ddot{\mathbf{x}}+\mathbf{C}^*(\mathbf{x},\dot{\mathbf{x}},\mathbf{Q}_t)\dot{\mathbf{x}}+\mathbf{G}^*(\mathbf{x},\dot{\mathbf{x}},\mathbf{Q}_t)=\boldsymbol{\tau}, \qquad (6)$$

Where M*, C*, and G* are considered as a continuous but unknown. M* is a positive definite matrix. The desired trajectory X_d (t) of the system is a bounded function of time 2 . The approximate dynamic model of the system can be provided as

$$\mathbf{M}_s(\mathbf{x})\ddot{\mathbf{x}}+\mathbf{C}_s(\mathbf{x},\dot{\mathbf{x}})\dot{\mathbf{x}}+\mathbf{G}_s(\mathbf{x},\dot{\mathbf{x}})=\boldsymbol{\tau}\,. \qquad (7)$$

The tracking error is given by $\mathbf{e}(t)=\mathbf{x}_d(t)-\mathbf{x}(t)$, and the sliding mode surface can be designed as follow

$$\begin{cases}\mathbf{s}=\dot{\mathbf{e}}+\mathbf{c}\mathbf{e}\\ \mathbf{c}=diag\{c_1,c_2,c_3,c_4\},\;\; c_i>0\end{cases} \qquad (8)$$

By designing the control law as

$$\begin{cases}\boldsymbol{\tau}=\mathbf{Y}_s+\mathbf{v}\\ \mathbf{Y}_s=\mathbf{M}_s(\ddot{\mathbf{x}}_d+\mathbf{c}\dot{\mathbf{e}})+\mathbf{C}_s\dot{\mathbf{x}}+\mathbf{G}_s+\dot{\mathbf{M}}_s\mathbf{s}/2\end{cases} \qquad (9)$$

We have the Lyapunov function as

$$L=\mathbf{s}^{\mathrm{T}}\mathbf{M}\mathbf{s}/2\,. \qquad (10)$$

By evaluating the derivative of (10), we have

$$\begin{aligned}\dot{L}&=\mathbf{s}^{\mathrm{T}}\left(\mathbf{M}_s(\ddot{\mathbf{x}}_d+\mathbf{c}\dot{\mathbf{e}})+\mathbf{C}_s\dot{\mathbf{x}}+\mathbf{G}_s+\frac{1}{2}\dot{\mathbf{M}}_s\mathbf{s}\right)-\mathbf{s}^{\mathrm{T}}\tau\\ &=\mathbf{s}^{\mathrm{T}}\left(\mathbf{Y}_s-\mathbf{Y}^*+\mathbf{Y}^*\right)-\mathbf{s}^{\mathrm{T}}\tau\\ &=\mathbf{s}^{\mathrm{T}}(\mathbf{Y})-\mathbf{s}^{\mathrm{T}}\left(\tau-\left(\mathbf{Y}_s-\mathbf{Y}^*\right)\right)\\ &=-\mathbf{s}^{\mathrm{T}}\left(\mathbf{v}-\left(\mathbf{Y}_s-\mathbf{Y}^*\right)\right)\\ &=-\mathbf{s}^{\mathrm{T}}\left(\mathbf{v}-\boldsymbol{\varepsilon}_s\right)\end{aligned} \qquad (11)$$

From (11) we get

$$\mathbf{Y}^*=\mathbf{M}^*(\ddot{\mathbf{x}}_d+\mathbf{c}\dot{\mathbf{e}})+\mathbf{C}^*\dot{\mathbf{x}}+\mathbf{G}^*+\dot{\mathbf{M}}^*\mathbf{s}/2\,, \qquad (12)$$

IV. IMPEDANCE CONTROL OF MECHANICAL ARM

The above control law is formed for the system, the posture of the subject can be adjusted when the robot arms are in contact with the subject. However, it is difficult to adjust the position of the subject relative to the robot arms. Therefore, in this section, the method of adjusting the arm-position is proposed and simulated. As shown in Fig. 4, the controller mimics the movements of humans when they are holding the subject.

System adjusted the arm-position by release the subject, when the system in the released state, the subject is disengaged, the gravity is considered as a virtual drive for the subject to restabilize the system. To reduce contact impact, an impedance control strategy is required.

At the state of release, there is no force between the subject and the robot arms, then the dynamic equation of the system can be expressed as

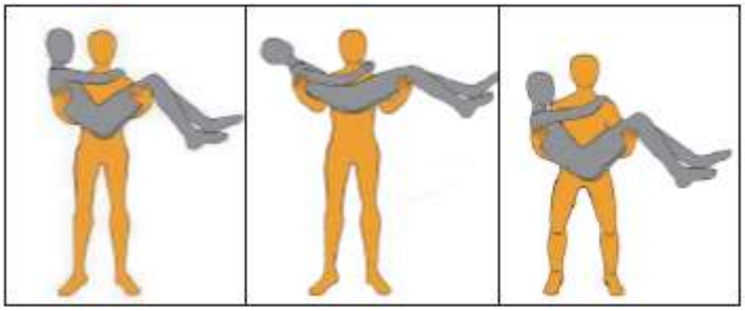
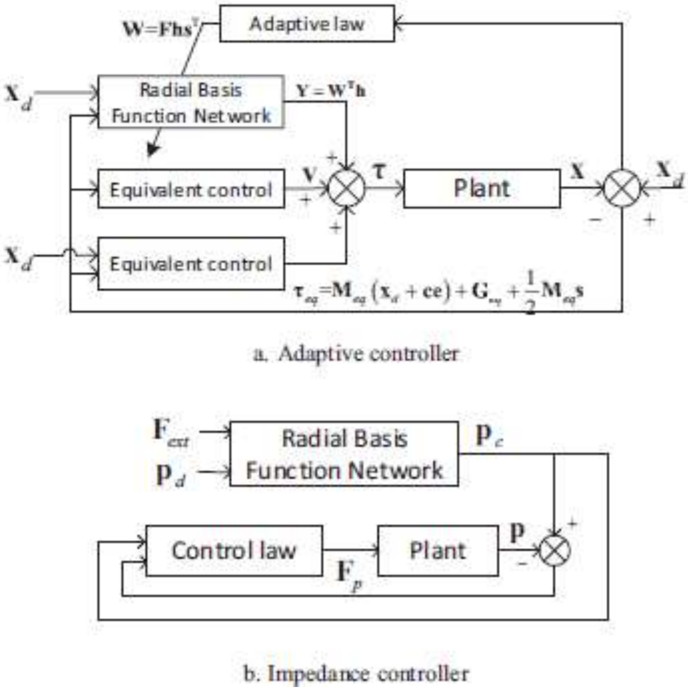


Fig. 4 Schematic diagram of arm-position adjustment

Where M is an inertia matrix, F_{ext} is the external force, and F_p is the input force.

V. NUMERICAL SIMULATION

The method introduced in this paper is applied to the model build by ADAMS, with system parameters shown in Table 1, which is applied for the simulation. Additionally, the controller is established by MATLAB as shown in Fig .5. Simulation are carried out, the first set is shown in Fig. 6, for the whole process of the system, the trajectory of robot arms and human body in the process of manipulation are obtained. The contact force on human body at different stages in the process of manipulation is shown in Fig. 7.

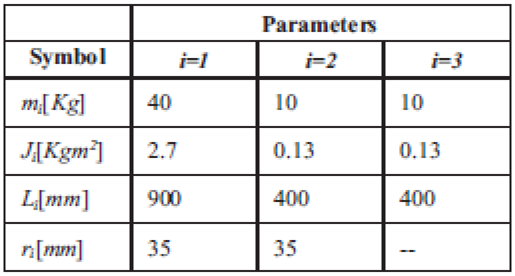


a. Adaptive controller

b. Impedance controller

Fig.5 Closed loop system with controller

TABLE I PHYSICAL PARAMETERS OF THE SYSTEM



	Parameters		
Symbol	***i=1***	***i=2***	***i=3***
$m_i[Kg]$	40	10	10
$J_i[Kgm^2]$	2.7	0.13	0.13
$L_i[mm]$	900	400	400
$r_i[mm]$	35	35	--

The first set shown in Fig. 6 is a realization of arm-position and posture adjustment through switching the adaptive and implement controllers. Firstly, the subject is accelerated along the vertical direction to separate the robot arms and the subject within 0.5 seconds. Secondly, the robot arms are deceleration to separate from subject, then robot arms can without contacting the subject, therefore adjust the relative position between the subject and robot arms. Finally, reduce the speed of the manipulator and the subject is accelerated by gravity, the subject re-contact with the manipulator, and there is a velocity difference at the moment of contact, the system is re-stabilized under the influence of impedance control and gravity of the subject, impedance control stabilize the system and reduce the impact force between the robot arms and the subject at the same time. We can observe that the actual trajectory of the restabilized system cannot follow the ideal trajectory perfectly, cause of the robot arms adjust its trajectory according to impedance control to ensure the conformance of human, reduce the impact force produced by re-contact.

The contact forces of whole simulation process are given as Fig. 7, we can see the impact of the moment of re-contact and how fast impedance control slows down this force.

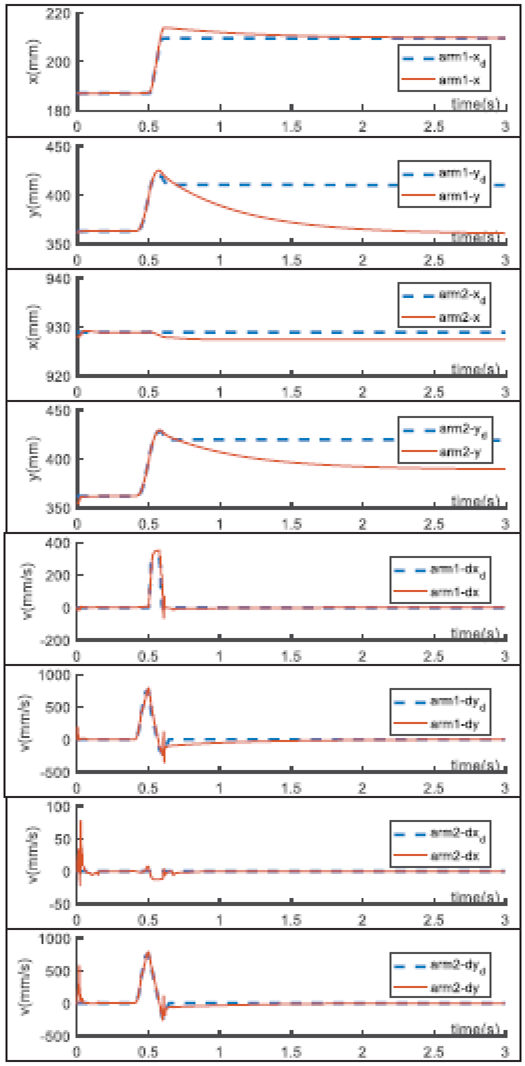


Fig. 6 Position and Velocity tracking of robot arms

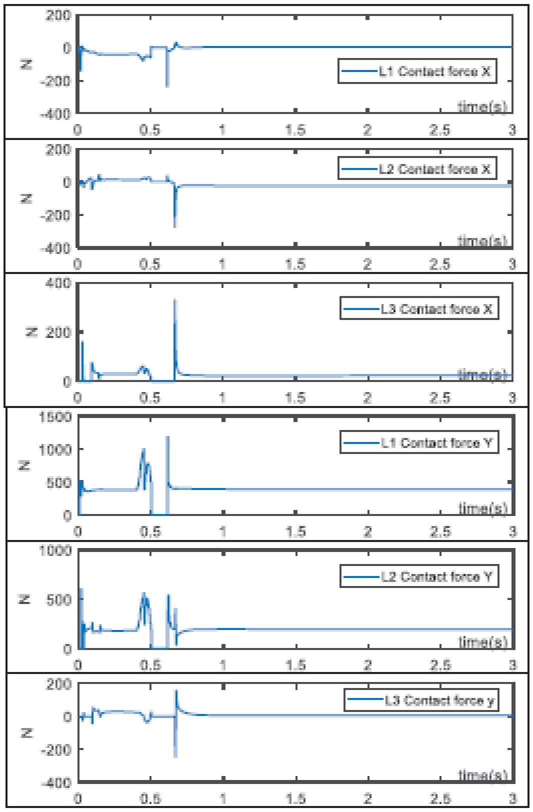


Fig. 7 Contact force between human body and robot arms

VI. CONCLUSION AND RECOMMENDATIONS

A novel control strategy to manipulate a multi-link objects that models a subject who is held by a dual-arm nursing care robot. The manipulation was divided into posture adjustment of the subject in holding and arm-position adjustment when the arms leave the subject for an instance to avoid friction. A neural network was introduced to build the control model, in which gravity is modeled as a virtual drive to the subject in the model. The posture adjustment was realized by using a sliding mode control method and impedance control was introduced in arm position adjustment.

The control law is switched according to the station. In the hold state, an approximate term of the neural network adaptive control law is used and in the release state, an impedance controller is introduced to ensure the comfort and safety of the subject. The effectiveness of the proposed method was confirmed by a numerical simulation.

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