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Human Assistance Robot Control by Artificial Neural Network for Accuracy and Safety

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Abstract— **A new accurate and reliable human-in-the-loop control by artificial neural network (ANN) for human assistance robot was proposed in this paper. The principle of human-in-the-loop control by ANN was explained, including the system architecture of human assistance robot control, the design of the controller, the control process as well as the switching of the different control patterns. Based on the proposed method, the control of meal assistance robot was implemented. In the controller of meal assistance robot, a feedforward ANN controller was designed for the accurate position control. For safety, a feedback ANN forcefree control was installed in the meal assistance robot. Both controllers have taken fully into account the influence of human arm upon the meal assistance robot, and they can be switched smoothly based on the external force induced by the challenged person arm. By the experimental and simulation work of this method for an actual meal assistance robot, the effectiveness of the proposed method was verified.**

I. Introduction

Nowadays, development of human assistance robot for welfare enterprise is one of attractive topics in robotics. Motor assistance is thought as the most possibly implementation with the current robot techniques. Actually, in present society, movement obstacle caused by spinal cord disease or neurological disabilities does widely exist. And it puzzles the daily life heavily of old persons and patients. It is always suggested to name them as challenged persons. They have to accept nursing from caretakers. Therefore, some efficient motor assistance may improve their living remarkably. Even a simple behavior made independent would bring them great motivation, privacy and dignity in their lives.

In recent several years, the research on human assistance robot was carried out widely in academic institutes or industries [1][2]. Same purpose mentioned above is being held by researchers from the various directions of view. In our laboratory, because of long-term intimate collaboration with famous neurobiological doctors and advanced robot making company, human assistance robot driven by neurobiological signal is achieved [3]. Different types of human assistance robots have been developed and plenty of research achievements on neurobiological signal detection and human desire extraction have been fulfilled, by which human assistance robot can be implemented and further study can be extended. As one of the approaches, a scheme for realizing accurate and reliable human assistance robot control by artificial neural network (ANN) was presented for constructing a human-friendly assistance robot and meanwhile guaranteeing the safety of human movement with the assistance from robot.

In this paper, a human assistance robot controller with ANN was constructed to realize accurate and reliable control of human assistance robot. For accurate position control, feedforward ANN controller for compensating the impact of human force as well as the dynamics of human assistance robot with many unknown factors was adopted. For safety of human movement, feedback ANN forcefree control was installed in the human assistance robot system. The proposed method was successfully used for meal assistance robot. Experimental and simulation results were illustrated to verify the effectiveness of the proposed method.

II. Method

A. System architecture of human assistance robot control

A human assistance robot is usually described from the aspects of kinematics and dynamics. Since human body is always attached to a human assistance robot in the motor assistance, there has close spatial relation between the human assistance robot and the human body. Therefore, we define the inter-relative kinematics of the human assistance robot with human body as [4]

$$\mathbf{P}^{HR} = f^{HR}(\mathbf{L}^{HR}, \mathbf{Q}^{HR}) \tag{1}$$

where $\mathbf{P}^{HR}$, $\mathbf{L}^{HR}$, $\mathbf{Q}^{HR}$ respectively denote the positions of human assistance robot with human body in the Cartesian coordinate, the lengths of human assistance robot links with human body as well as the positions of human assistance robot with human body in the joint coordinate.

Since challenged persons have almost lost their abilities of movement, when performing the movement of human bodies by the actuation from human assistance robot, human assistance robot provides a master dynamics, but the human body merely has a slave dynamics due to his mass and structure. Therefore, we proposed the master-slave dynamics of human assistance robot with human body by supposing the human body as a load of human assistance

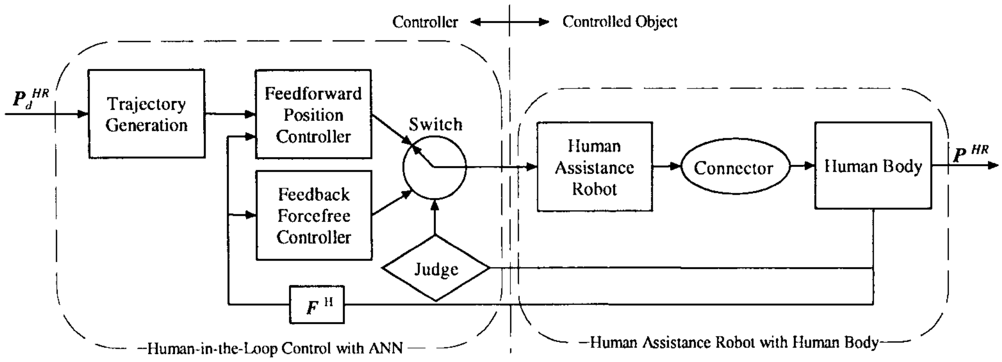

Fig. 1. Function block diagram of the proposed method

robot. It can be defined as

$$W^{HR}(\mathbf{L}^{HR}, \mathbf{M}^{HR}, \mathbf{Q}^{HR}, \dot{\mathbf{Q}}^{HR}, \ddot{\mathbf{Q}}^{HR}) = \mathbf{\Phi}^{HR} \quad (2)$$

where $\mathbf{L}^{HR}, \mathbf{M}^{HR}, \mathbf{Q}^{HR}, \dot{\mathbf{Q}}^{HR}, \ddot{\mathbf{Q}}^{HR}, \mathbf{\Phi}^{HR}$ denote the length, mass, joint position, joint velocity, joint acceleration, torque of robot links with human body, etc.

With this model, we constructed the human assistance robot control system. As illustrated in Fig.1, the system architecture of human assistance robot can be divided into several blocks. Trajectory generation refers to the objective trajectory generation of human assistance robot with human body based on the external command P_d^{HR}, which can be generated by neurobiological signals, signals of buttons, etc. The controller of human assistance robot is composed of two parts: feedforward position controller and feedback forcefree controller. The feedforward position controller is to realize accurate movement along the objective trajectory. The control signal of position controller directly drives the servo motor of human assistance robot to output a strong enough force to human body. The forcefree controller is installed in the overall system for the safety of human movement [5]. If there appears a strong force from human body or external circumstance, the movement of human assistance robot along the objective trajectory should be gradually switched into the movement actuated by the external force. The force from the human assistance robot itself, such as gravity, friction, etc., should be decreased in order to avoid the harm to human. Therefore, the purpose of forcefree controller is to implement the movement of human assistance robot actuated by the external force and compensate the force from human assistance robot itself. Obviously, the switching of position controller and forcefree controller is based on the measurement of external force. The judgment for switching is according to the pre-defined threshold of force.

Besides, the proposed method is a kind of human-in-the-loop control. Both the feedforward position control and the feedback forcefree control are taking into account the impact of human force. In the position control, the torque from the human force is added into the torque generated by the servo motor to actuate the movement of human assistance robot with human body. In the forcefree control, the movement of human assistance robot with human body is directly actuated by the human force. With this control pattern, the constructed human assistance robot has a well human-friendly interface between the robot and the human.

Since there have following requirements, artificial neural network (ANN) is employed to construct position controller and forcefree controller: (a) control human assistance robot to move accurately along the objective trajectory; (b) adapt to characteristics of challenged person movement; (c) compensate the influence of unknown factors upon the human assistance robot; (d) guarantee the safety of human movement; (e) realize real-time flexible control.

B. Implementation of human assistance robot control by artificial neural network

In the feedforward position controller, the compensator for the inverse dynamics of human assistance robot with human body is constructed with ANN based on the master-slave dynamics of human assistance robot with human body. Since there are many unknown factors varied by the human force as well as the human assistance robot, actual data on human assistance robot with human body obtained from the experiment are used to train the weights of ANN, so that the control performance of feedforward position controller can be improved. Besides, the generated driving torque is composed of not only the torque for driving human assistance robot, but also the torque for driving human body. It is described by

$$(\tau^{HR})^{force} = \tau^R + \tau^H \quad (3)$$

where $(\tau^{HR})^{force}$, τ^R and τ^H denote the input torque of the human assistance robot with human body, the torque for driving human assistance robot and the torque for driving the human body. We usually use a force sensor or a

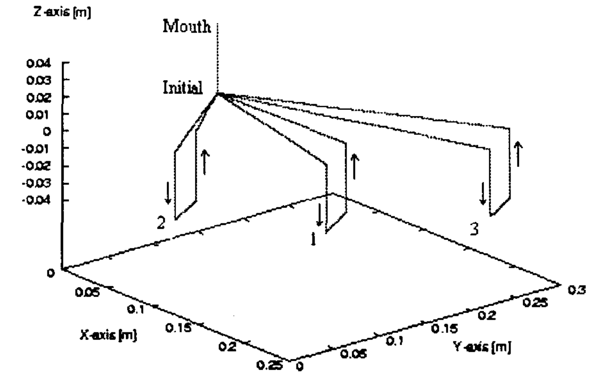

Fig. 2. Experimental results on the locus of the tip of meal assistance robot

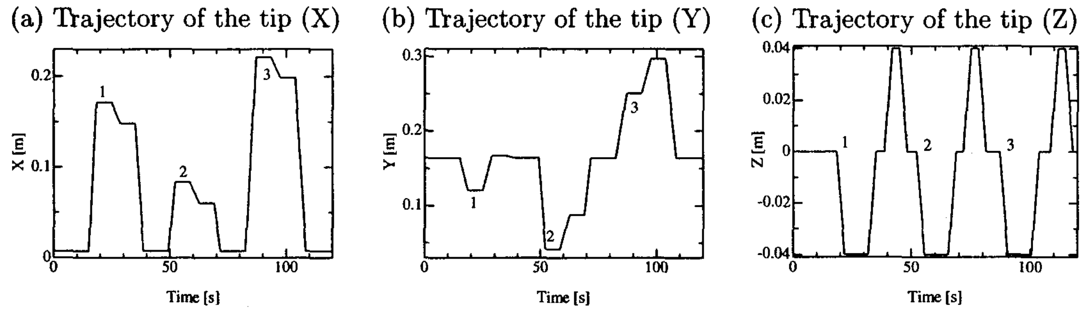

Fig. 3. Experimental results on the actual trajectory of the tip at the X, Y, Z axis

torque monitor to measure the values of output torque from the human body. These values are adopted as the torques for driving human body. In the human-in-the-loop control of the human assistance robot, the output torque of human body is taken into account in the control input all along in order to adapt to the various kinds of subjects.

In order to ensure the safety of human movement, the feedback forcefree controller is installed in the control system [5]. It can be described by

$$(\gamma^{HR})^{forcefree} = \gamma^E + \gamma^F + \gamma^G \tag{4}$$

where $(\gamma^{HR})^{forcefree}$, γ^E, γ^F, γ^G denote the input torque for human assistance robot, the torque from human body, the torque of friction and the torque of gravity. In the proposed method, we also use ANN to construct a feedback forcefree controller. The task of ANN in the feedback forcefree controller is to compensate the torque for human body and the torque of friction because these two kinds of torques are variable in the control process.

In the control process of human assistance robot, firstly, an objective position $P_d^H(x^H, y^H, z^H)$ is given according to the input command and an objective trajectory is then generated. Using the inverse kinematics, the objective trajectory is transformed from the Cartesian coordinate into the joint coordinate. Next, by judging the human force F^H, the control process enters into the control loop. If the human force F^H is not greater than a threshold, the control process enters into the position control loop. Otherwise, it enters into the forcefree control loop. In the position control loop, the objective control torque τ_d^{HR} is firstly generated by the ANN position controller. With the servo controller, the control signal $(q_d^R)^{force}$ is generated. Then the control signal is put into the actual human assistance robot to implement the motor assistance. If no big human force, the position control will continue to perform until the assistance task is fulfilled. Otherwise, it will temporarily turn into the forcefree control loop. As the same as the position control loop, the control torque γ_d^{HR} is firstly generated by ANN forcefree controller. With the servo controller, the control signal of forcefree control $(q_d^R)^{forcefree}$ is generated, and then put into the human assistance robot to perform the forcefree control. If the human force becomes smaller than the threshold, the forcefree controller loop will turn back to the position control loop.

For realizing the switching between two kinds of control smoothly, a switching method of controller according to the external force induced by the challenged person is

$$q_d^{HR} = (1 - \alpha t)(q_d^{HR})^{force} + \alpha t (q_d^{HR})^{forcefree} \tag{5}$$

where q_d^{HR} is the total input of human assistance robot with human body. $(q_d^{HR})^{force}$ is the input of human assistance robot with human body generated only by the position controller. $(q_d^{HR})^{forcefree}$ is the input of human assistance robot with human body generated only by the forcefree controller. α is the ratio between the input generated by the position controller and the input generated by the forcefree controller. t is the switching time. Within the switching period defined beforehand, the switching process will be carried out smoothly between two controllers.

III. Application: Control of Meal Assistance Robot

The proposed human assistance robot control system was actually adapted for the control of meal assistance robot. The task of meal assistance robot is to assist human to move his arm between the mouth and the dishes. The human desire of eating was extracted from the Electrooculogram (EOG) and the meal assistance robot arm assisted the human arm to move according to the human desire. The controller of meal assistance robot is designed based on the master-slave inter-relative model of meal assistance robot with human arm [4]. It comprises of a feedforward ANN position controller and a feedback ANN forcefree controller. The ANN position controller has four input nodes, representing the objective trajectory, velocity, acceleration and unknown factors, eight hidden nodes and one output node, representing the control torque. The ANN forcefree controller is consisted of a ANN for representing the torque of human force as well as friction and a model of gravity. The training of ANN controllers are all based on the actual data obtained from the actual movement of meal assistance robot. The switching of two kinds of controllers is based on the judgment of external forces.

The proposed method is experimentally adopted for a meal assistance robot. Fig.2 illustrates the experimental results on the locus of the tip of meal assistance robot. Fig.3 illustrates the experimental results on the actual trajectory of the tip at the X, Y, Z axis. The movement of meal assistance robot with human arm is well consistent with the objective trajectory.

For confirming the safety of meal assistance robot, we made a simulation work, in which a big human force is supposed to be appeared during the period of movement of meal assistance robot with human arm along the objective trajectory. From Fig.4, we can see that there appears a big human force at about the moment of 80[s]. The forcefree control is automatically switched into the system from the position control. The robot is moving by the actuation of human arm. After several seconds, with the disappearing of the human force, the meal assistance robot is continuously performing the movement of meal assistance. Therefore, based on these results, the human arm can be moved precisely and safety with the assistance from meal assistance robot even there exist big human forces.

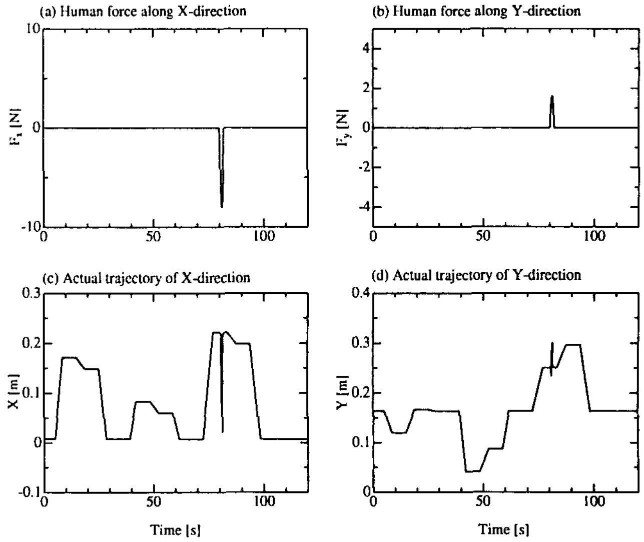

Fig. 4. Simulation results of the proposed method with big human forces

IV. Conclusion

A scheme for realizing accurate and reliable human-in-the-loop control by artificial neural network for human assistance robot was proposed. With this method, human can move his body accurately and reliably because of using position control and forcefree control. Even there exist impact of human force and many kinds of unknown factors as well, ANN controller can overcome them by learning from the actual movement of human assistance robot with human body. Because of using forcefree control, the harm from of human assistance robot to human body can be avoided. With the application of the proposed method for a meal assistance robot, the effectiveness of the proposed method was verified. Further, this method can be extended for many other kinds of human assistance robots.

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