1207 Control of an Exoskeleton Robot for Human Wrist Motion Support
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Abstract
In this paper we propose an EMG-Based control of a three degree of freedom (3-DOF) exoskeleton robot for the forearm pronation/supination motion, wrist flexion/extension motion and ulnar radial deviation. The skin surface electromyographic (EMG) signals of muscles in forearm of the exoskeleton’s user and the hand force/forearm torque are used as input information for the proposed controller. By applying the skin surface EMG signals as main input signals to the controller, automatic control of the robot can be realized without manipulating any other equipment. Fuzzy control method has been applied to realize the natural and flexible motion assist. An experiment has been performed to evaluate the proposed exoskeleton robot.

1. Introduction
The upper-limb motions (shoulder, elbow, and wrist motion) are especially important for people to perform daily activities. The exoskeletons for elbow motion assist [1], shoulder motion assist [2], upper-limb motion assist [3][5][6] and elbow and forearm motion assist[4], have been proposed for daily use or rehabilitation up to the present. This paper presents an exoskeleton robot for wrist flexion/extension motion, ulnar/radial deviation and forearm pronation/supination motion assist for physically weak people. The forearm pronation/supination motion, wrist flexion/extension motion and ulnar/radial deviation, which are essential motions for the daily activities, are assisted by the proposed exoskeleton.

Although many exoskeletons have been proposed for wrist motion assist [6][9], there are undesired problems in their design. For example, the axes offset of flexion/extension axis and ulnar/radial deviation axis is not taken into account in the existing robots [8] [9], although it is important for the wrist exoskeleton to avoid the undesired pain for users. The robot user has to grip a link (palm holder) for wrist motions in almost all of the existing exoskeleton robots [6] [8] [9] (except ASSIST [7]), so that users’ fingers won’t be able to use for other purposes. The proposed exoskeleton robot is designed considering the above shortcomings and its’ palm holder can be worn and the user does not have to grip it.

The electromyography (EMG) signals of human muscles are important signals to understand the motion intention of human. Therefore, the EMG signals can be used as input information for the control of many robotic systems [10]-[12]. The skin surface EMG signals of muscles in forearm of the exoskeleton’s user are used as main input information for the control of the proposed exoskeleton robot. The hand force (Generated force between the robot and the hand of the robot user) and forearm torque (Generated torque between the wrist holder of the robot and the forearm of robot user) are also used as subordinate input information for the controller. Since the forearm, consist of many kinds of muscles which are involved in many motions [13], it is difficult to apply EMG signals of muscles of the forearm as input signals to the controller. Fuzzy IF-THEN control rules have been newly designed after experimentally finding out the patterns of EMG signals for the motion of forearm and wrist. The fuzzy controller has been applied for the control of the proposed exoskeleton robot to obtain natural and flexible motion control.

2. Hardware Design of Exoskeleton
Figure 1 shows the proposed exoskeleton robot for human wrist and forearm motion assist. The proposed exoskeleton robot mainly consists of a forearm motion support part and a wrist motion support part, and it is directly attached to the user’s forearm. The wrist motion support part consists of a link attachment, two DC motors, two drive and driven bevel gear pairs (Gear ratio-1:2), a palm holder, a three axis force sensor and a link (LINK-3) which connect the palm holder and link attachment as shown in Fig. 1.

![Fig. 1 3-DOF wrist and forearm motion power assist exoskeleton robot](image)

The forearm motion support part consists of two links (LINK-1 and 2), a DC motor, a drive and driven spur gear pair (Gear ratio-1:3), a wrist holder, a forearm cover and torque sensors (Strain gauges). More details of the hardware design can be referred in [14].

3. Controller
The proposed exoskeleton robot is controlled based on the EMG signals and the hand force/forearm torque. In the proposed control method, the motion assist is carried out based on the hand force/forearm torque when the amount of the EMG activity levels is low. By applying sensor fusion with the EMG signals and the hand force/forearm torque, the error motion caused by little EMG levels and the unexpected motion caused by the external force affecting to the user’s arm can be avoided [1][3][4]. Since the difficulty of predicting the wrist motion intention of the user based on the EMG signals of the muscles involved in wrist motion, fuzzy control has been applied to realize flexible and real time control based on the EMG signals.

![Fig. 2 Locations of electrodes](image)
06 kinds of EMG signals are measured to control the wrist flexion/extension motion, ulnar/radial deviation, and forearm supination/pronation motion as shown in Fig. 2. 02 of the channels (ch.4 & ch.5) are used to figure out the wrist flexion motion, other 02 of them (ch.2 & ch.3) are used to figure out the wrist extension motion and 02 of them (ch.3 & ch.5) are used to figure out wrist ulnar deviation and other two of them (ch.2 & ch.4) are used to figure out wrist radial deviation. In addition, ch.1 and ch.6 are used to figure out forearm supination and pronation motions respectively. Since there is difficulty in using raw data of EMG for input information of the controller, features have to be extracted from the raw EMG data. In this study, Root Mean Square (RMS) has been applied as the feature extraction method for the EMG levels for the fuzzy controller[15]. The input variables for the controller are RMSs of 06 kinds of the EMG signals and the generated hand force/forearm torque measured by the force/torque sensors.

In the control rules, it was considered the generated hand force/forearm torque are more reliable when the exoskeleton’s user activates the muscles little (EMG levels of the user are low), and the EMG signals are more reliable when the user activates the muscles a lot (EMG levels of the user are high) [1] [3] [4]. Consequently, the exoskeleton robot can be controlled in accordance with the human user’s intention. By applying sensor fusion with the EMG signals and the generated hand force/forearm torque, error motion caused by little EMG levels and the external force affecting to human arm can be avoided. 03 kinds of linguistic variables (Z0: Zero, PS: Positive Small, and PB: Positive Big) are prepared for each RMS and 05 kinds of linguistic variables (NB: Negative Big, NS: Negative Small ZO: Zero, PS: Positive Small, and PB: Positive Big) are prepared for each force/torque signals. 46 kinds of fuzzy IF-THEN rules are defined for the controller [15] in this study. When the exoskeleton’s user does not activate the muscles for wrist and forearm motions force control of the hand force/forearm torque are performed.

4. Experiment
An experiment has been performed with a young healthy male subject to prove the effectiveness of the proposed exoskeleton robot. The experimental setup is shown in Fig. 3. It consists of the robot and human subject, three motors with encoders, a personal computer (PC) with an interface card (JIF-171-1), an EMG amplifier, a strain amplifier, two motor drivers (each has two channels) and power suppliers. In the experiment, wrist and forearm motions were performed with and without assist of the robot. In the first experiment, the subject performed wrist extension/flexion motion. The activation levels of the muscle of extensor carpi radialis brevis (ECRB) with and without the assist of exoskeleton are shown in Fig. 4 (a) and (b), respectively.

From the activation levels of ECRB it can be clearly seen that the activation levels decreased, when the exoskeleton robot assisted the motion. The experimental result for forearm pronation/supination motion is shown in Fig. 5. From the experimental results one can clearly see that the motions are smooth and the muscles activation levels decrease when the exoskeleton robot assisted the motions.

5. Conclusion
Control system of a 3 DOF exoskeleton robot, based on skin surface EMG signals was proposed to assist wrist and forearm motions of physically weak individuals. The exoskeleton robot generates the smooth natural motions of forearm pronation/supination, wrist flexion/extension and ulnar/radial deviations and daily motions in accordance with user’s motion intention. The experiments showed the effectiveness of the exoskeleton robot to assist wrist and forearm motions.

References