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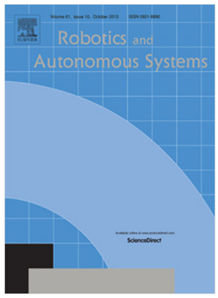

An innovative robotic training system imitating the cervical spine behaviors during rotation-traction manipulation

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An innovative robotic training system imitating the cervical spine behaviors during rotation-traction manipulation

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***Abstract* - The present study demonstrated an innovative humanoid robot applied during Rotation-Traction (RT) manipulation practice and evaluation process. A mass-damper-spring mechanical system with an electromagnetic clutch was designed to emulate the cervical spine and a 3-DOF non-planar model was built to replace the neck part. With the help of an excellent electromechanical system and appropriate control strategy, the robot could imitate the entire dynamic responses of the human cervical spine during the RT manipulation process. Moreover, a novel adaptive force tracking impedance control was adopted to ensure a variable contact force in the unknown environment to imitate the real biomechanics of the human neck. In comparison to existing impedance control methods, the proposed control scheme is not only utility but also robust against external disturbances such as varying stiffness or uncertainties of the robot. The stability of the proposed impedance control was theoretically examined. Test results revealed that the cervical spine robot could faithfully replicate the biomechanical properties of the human cervical spine during RT manipulation and it is helpful in training and evaluating interns.**

Index Terms - robotics; adaptive impedance control; rotation-traction manipulation; cervical spine model; biomechanical;

1. INTRODUCTION

Cervical spondylosis is a common and noteworthy disease of the cervical spine, which is part of the aging process and affects most people [1]. More specifically, 95% of patients by the age of 65 years old are suffering from degenerative disorders of the spine [2]. Symptoms such as neck pain or stiffness, numb and/or clumsy hands, weakness, bilateral arm paresthesia and gait impairment may occur because cervical spondylosis can affect the intervertebral disks, vertebrae, facet joints and ligamentous structures that encroach even spinal cord [1, 3]. However, most surgical approaches are still controversial and can cause undesirable side effects [4]. Together with drug therapy, cervical traction as a nonsurgical regimen constitutes the mainstay of the treatment especially when the motor weakness is primitive and insignificant [5]. Rotation-Traction (RT) manipulation is a significant traditional Chinese medicine nonsurgical technique for cervical spondylosis, which has the characteristic of riskless and fast operation and effective therapeutic modalities [6]. A systematic and scientific manipulation process has been well created by Wangjing Hospital at the Chinese Academy of Traditional Chinese Medicine and RT manipulation can loosen adhesions within the intervertebral space, reduce compression and irritation of discs, and improve circulation in the epidural space of the neck [7]. As a clinical treatment, RT manipulation required a strict operational specifications. However, the majority of interns lack practical experience and real treatment operation, which can cause inadvertent errors, resulting in medical malpractice events ranging from soft tissue contusion to serious spinal injury. Therefore, a device that is able to simulate the biomechanical characteristics and substitute for a real human spine is required during RT manipulation. The integrated process of the manipulation could be composed into distinct steps and evaluated by technical index via this particular device.

Automation, control theory, mechanical technique and medical technology continue to integrate; therefore, robotics is an emerging comprehensive technology that can be applied in the clinical medicine area. To simulate the human cervical spine, accurate biomechanics characteristics should be taken into account. Because living tissue contains the load-transmitting mechanism, mechanical principle and control strategy can be applied to solve biomechanical problems [8]. On the one hand, the biomechanical behaviors of the cervical spine have been studied from different aspects. Both the variation characteristics of external forces and the internal stresses and strains have been measured in high-velocity, low amplitude manipulations in a variety of experiments [9]. Mathematical models of the cervical spine have been assumed as the lumped parameter type and the neck has been modelled as a collection of spring, damper and mass [10]. The desired mechanical parameters such as displacement, velocity, acceleration and external force have been directly measured by dedicated sensor systems [11, 12]. Furthermore, the neck finite element model has been built for biomechanical analysis [13]. Besides, optimization method has been applied on the mechanic design [33, 34, 35]. On the other hand, a suitable control scheme is indispensable for regulating the contact force and relative motion between the robot and physician to