Under-actuated Hand Exoskeleton with Novel Kinematics for Potential Use in Rehabilitation

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***Abstract*—We present an under-actuated hand exoskeleton with novel kinematics for potential use as home-based robotic rehabilitation device. The device is wearable, portable and ergonomic. It applies individual resistive forces to the extension/flexion of the fingers through serial kinematics chains attached to the distal phalanges of the fingers. Moreover, it has its own tracking system which gives an accurate position and orientation of the fingertips. The exoskeleton has been integrated into a Virtual Reality hand environment where a virtual representation of users' hand, while grasping and manipulating virtual objects, is displayed. The inverse kinematic model of the fingertips has been used to obtain a realistic configuration of the virtual hand.**

Keywords—rehabilitation; hand exoskeleto; virtual reality

I. Introduction

Robot assisted rehabilitation therapies offer several advantages with respect to conventional rehabilitation therapies [1], [2]. Some of these advantages include: execution of intensive and repetitive therapeutic exercises, can implement novel training methods that can be adapted to the patient needs and an accurately and repetitive measurement of patient performance.

Studies have demonstrated that increasing the therapy intensity (timing and dose) can improve the patients rehabilitation [3], [4]. In practice, however, this is difficult to achieve since patients need to go the hospital to execute their robotics-assisted therapy program. This is mainly due to the fact that most of the existing robotic rehabilitation devices are available only for clinical use due to their lack of portability and wearability. To allow patients to exercise more intensively and periodically, efforts should be made towards the development of light weight and portable robotic rehabilitation devices that can be use at home.

In this paper, a hand exoskeleton that overcomes the problems of wearability, portability and ergonomy, and for potential use in rehabilitation is introduced (Fig. 1). Its design is based on a highly under-actuated mechanism and provides tracking and bidirectional force feedback to the distal phalanges of the users' fingers through serial kinematic chains. The device has been integrated into a Virtual Reality (VR) hand environment, where patients can see reflected their hand movements, position and orientation while performing their therapeutic exercises. By using an inverse kinematic model of the patients' fingertips, a realistic virtual representation of their hand and fingers has been generated.

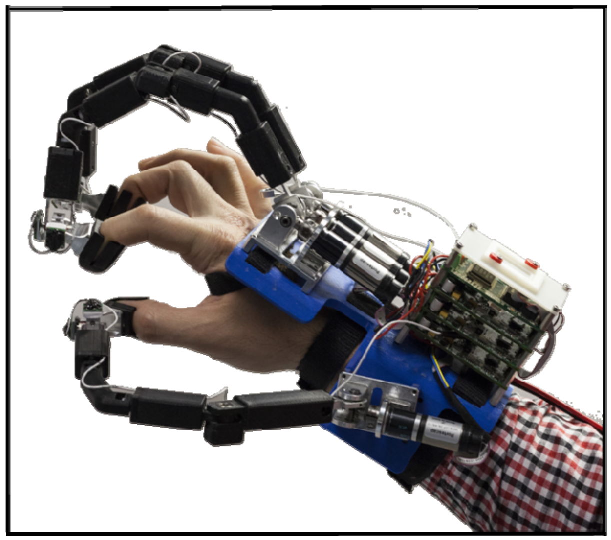

Fig. 1. Hand Exoskeleton with serial kinematic chains attached to the distal phalanges.

II. Hand Exoskeleton

The hand exoskeleton is a highly under-actuated system with novel kinematics that can potentially be used for rehabilitation of the hand, see Fig. 1. The device provides tracking and force feedback to the thumb and two fingers, although its mechanical structure can be easily extended to the other two fingers. Feedback forces are transmitted to the distal phalanges of the user's fingers through 6 DOF serial kinematic chains (with 5 passive and 1 active revolute joints), see Fig. 2. These chains are grounded on one side, and on the other side are attached to the distal phalanges of the fingers through interchangeable thimbles. This single point of attachment of the links to the fingers allows for fast and easy donning and removal of the device and keeps the palm, the phalanges and joints free of mechanical obstructions. The linkage kinematics provides 6 DOF (3 rotations and 3 translations) to the fingertips and, with respect to other hand exoskeletons, it allows the fingers to have a more natural postures. The kinematics of the system support variable hand sizes without having to modify or adapt the linkage lengths, furthermore the thimbles are easily interchangeable with a snap-on mechanism for accommodating different finger sizes. The wearability, comfort and usability of the hand exoskeleton may allow for its use as a home-based device.

The device provides individual controlled resistive force to the fingers. The applied force can oppose flexion or assist extension of the fingers. It incorporates a force sensor (strain gauge) per link to measure the force applied to the fingers. The bidirectional actuation is provided by backdrivability low gearing motors at the first revolute joint of each linkage. The actual actuation system provides approximately 3N at the fingertips when the finger is fully extended, although we are already working on a new design with a cable-driven actuation that will apply higher forces. The exoskeleton integrates its own tracking system through rotary magnetic position encoders embedded in the linkage joints which allows measurement of the position and orientation of the fingertips, see Fig. 2.

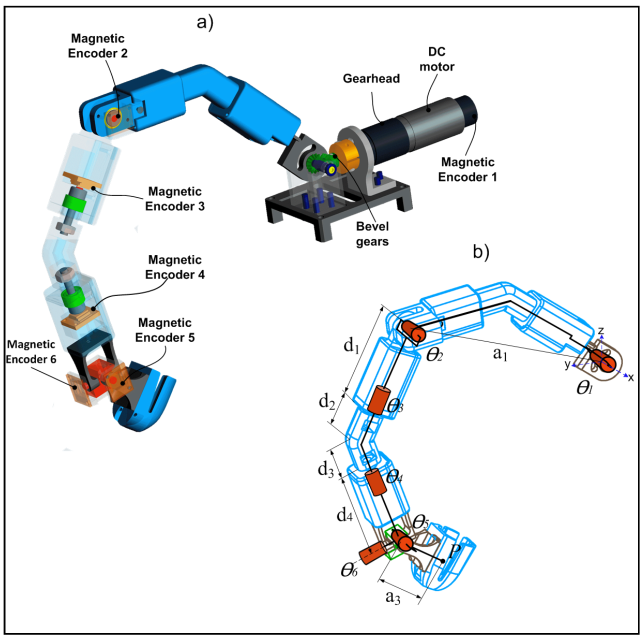

Fig. 2. a) Tracking and actuation, and b) kinematics of the serial linkages attached to the index finger.

III. Virtual Reality Hand Environment

One important aspect to consider when developing a robotic rehabilitation system is the design of a variety of appealing and motivating exercises that may facilitate and enhance the motor rehabilitation [5], [6]. To provide a solution to this challenge we have developed a VR hand interface that provides visual, auditory and haptic feedback while users grasp and manipulate virtual objects. The graphical interface displays a virtual hand that reflects users' hand position, orientation and motions. The joint angles of the fingers are calculated from a simple inverse kinematic model of each fingertip. This model uses the position and orientation of the fingertips (obtained from the exoskeleton links forward kinematics) to determine the joints configuration. Further work will incorporate a more accurate kinematic model of the fingers and VR hand rehabilitation exercises based on daily living tasks and games.

A multi-point haptic rendering method is implemented in order to detect the collision between the virtual fingertips and objects and calculate the forces to be conveyed to the users' fingers. The collision detection was performed by implementing an AABB collision detection algorithm, whereas the estimation of the magnitude of the force feedback at each finger were accomplished by a proxy-based force rendering algorithm. The libraries of the open source platform CHAI3d were used to render the graphic scenario, detect collisions and render the force feedback when the object was encountered by the users' virtual fingers.

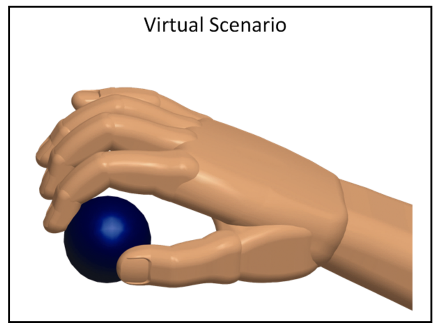

Fig. 3. VR hand environment reflecting users' hand posture.

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