

DESIGN OF A RAPID-PROTOTYPED SMART ROBOTIC EXOSKELETON FOR POWER WHEELCHAIR USERS

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ABSTRACT

Over 400,000 people in the United States use wheelchairs in their daily lives due to muscular diseases such as muscular dystrophy and cerebral palsy, injury, and stroke. Additionally, people with lower extremity weakness or paralysis due to these issues often have upper limb impairments as well, severely limiting their ability to do activities of daily living. There has been an increased interest in exoskeletons, particularly actively-actuated exoskeletons, to help augment activities of daily living for such persons; however, portability and accurately and intuitively deriving user intent have been limiting factors. We propose a compact, light-weight, and smart assistive 3 degrees of freedom wheelchair-mounted robotic upper arm exoskeleton to augment elbow and shoulder flexion/extension, as well as shoulder abduction/adduction joint movements. The novel smart controller system involves force sensing resistors to detect user intent, rotary encoders for joint feedback, and a user-interface system utilizing microcontroller technology to manipulate the wheelchair-mounted robotic upper arm exoskeleton. A prototype was designed and modeled using SolidWorks and fabricated using additive manufacturing, while stress and displacement were estimated using finite element analysis and end-effector workspace was calculated using Denavit-Hartenberg parameters in MATLAB. The current prototype uses joint angle limits based on biomechanical limitations and can be customized for particular user's range of motion. Workspace results show total range for the end-effector of 10.42, 13.16, and 69.6 cm in the X, Y, Z directions with rotations from -30 to 25°, -40 to 50°, and -30 to 50° of the first (shoulder abduction/adduction), second (shoulder flexion/extension), and third (elbow flexion/extension) joints, respectively. The overall weight of the proposed exoskeleton is under 3 kg. Finite element analysis showed areas along links of high stress which will be reinforced. An institutional review board application was approved to conduct testing on participants without disability in order to determine efficiency of the proposed exoskeleton. The results of initial human subject testing showed promise for the smart, force-input controller with successful actuation of each exoskeleton joint.

Keywords: upper limb exoskeleton, assistive technology, robotics, finite element analysis, kinematics, additive manufacturing

INTRODUCTION

Wheelchairs provide mobility to people suffering from muscular diseases such as Duchenne Muscular Dystrophy (DMD) and Cerebral Palsy (CP), injury and stroke, which also often impair upper limb movement as well. There are more than 400,000 people in the United States alone who use wheelchairs [1]. CP affects 2-3 out of every 1000 people born in the world [2]. Duchene muscular dystrophy, which affects muscles in the upper and lower limbs, occurs in 1 out of every 3500 males born in the US [3]. Altogether, in the US there are more than a million people with neuromuscular diseases that affect arm movements [4]. In order to augment activities of daily living (ADL) for such persons, exoskeletons have been growing in popularity as a solution. Limiting factors such as intuitiveness and accuracy of deriving user input for control, as well as portability and robustness of the exoskeleton have delayed the realization of the full potential exoskeletons have to impact ADL and allow those with disabilities to more completely live life and participate in the workforce.

There are three main types of exoskeletons: non-actuated, passively-actuated, and actively-actuated. A non-actuated exoskeleton, commonly known as an orthosis, is a brace-like functional support device designed for assisting movement [3]. This type of device typically supplies anti-gravity support, so that the user can move the arm horizontally, and help with elbow flexion and extension movement [5]. One of the first of these non-actuated exoskeletons is known as the Balanced Forearm Orthosis, which