16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line
dys-ta.com

Design and simulation of a lower limb exoskeleton with linear electric actuators

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Abstract: In the present study, we proposed and investigated a relatively simple and inexpensive construction of a lower limb exoskeleton driven by linear electric actuators and controlled by an Arduino microcontroller board. Moreover, to study crucial kinematic and dynamic parameters of the proposed device, we developed a general, three-dimensional simulation model of the exoskeleton in Mathematica software. To control individual joints of the investigated exoskeleton, we employed time histories of human joint angles in normal gait, recorded with the use of a motion capture system. As a result, we developed a novel human gait generator, which can be used to produce rhythmic movements in hip, knee and ankle joints of both limbs. Finally, the developed control approach was verified with the use of the constructed prototype of the exoskeleton.

Keywords: human lower limbs, exoskeleton, human movement

1. Introduction

Locomotor dysfunctions are common especially in highly developed societies, and the number of people suffering from such a kind of impairment is expected to grow in the future [1]. Although conventional physiotherapy helps restore mobility, it is labour-intensive and leads to occupational conditions among therapists. To overcome these drawbacks, lower limb rehabilitation can be performed with the aid of robots such as lower limb exoskeletons (LLEs). Information about developments and challenges in the field of LLEs can be found in review paper [2].

2. Results

We proposed and investigated a simple and economical lower limb exoskeleton aimed at rehabilitation. The device is driven by linear electric actuators. To realize the control algorithm, a popular Arduino microcontroller board is employed. Joints of the exoskeleton are driven according to time histories of human joint angles during normal gait recorded with a motion capture system [3,4].

A CAD model of the proposed LLE, created in Inventor Professional 2019, is presented in Fig. 1. Mechanical design consists of the main static pelvic frame, back part providing support for the upper body, and two limbs, each equipped with three linear actuators. A limb consists of three main segments actuated by active hip, knee and ankle joints. By changing the lengths of particular segments, it is possible to adapt the construction to people of different heights. Each active joint consists of a linear actuator with DC motor, gear ratio and screw-nut system.

To study the proposed LLE, we developed a 3D simulation model of the exoskeleton (see Fig. 1). The simulation model is fully parametric, therefore arbitrary values of all parameters determining the kinematic model of the exoskeleton can be applied to numerical study. As a result, the implemented simulation model can be used to visualize the mechanical design and verify the correctness of simulated results, namely the spatial positions of its elements. In a further study, it can help understand key parameters of virtual experiments of the prototype made of aluminium profiles.

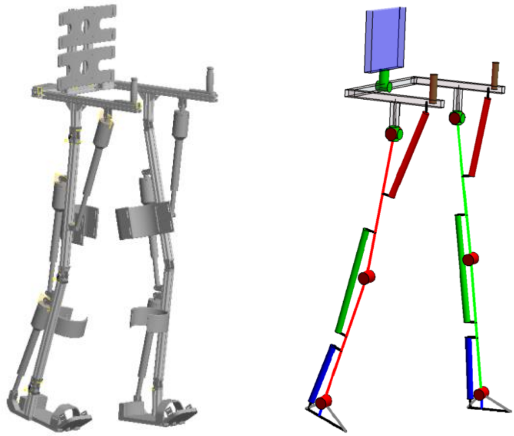

Fig. 1. CAD model of the designed LLE driven by linear actuators with DC motors, gear ratios, screw-nut systems and potentiometers (on the left), and a general, 3D full parametric simulation model of the LLE (on the right)

3. Discussion and conclusions

Both in the proposed design and the developed simulation model, we considered the biocompatibility aspects of the simulated device. As a result, in a further study, the developed simulation model can be successfully employed for more advanced and more accurate virtual studies of a walking process and determination of the most important kinematic and dynamic gait parameters. To verify the proposed control technique, a prototype of the LLE was constructed. The carried out experimental investigations gave promising results regarding control of the device in practical applications. To conclude, we showed that it is possible to develop relatively inexpensive and efficient LLE with a simple control system. The obtained results may contribute to a better access to LLE-assisted rehabilitation in the future and reduce the workload of physiotherapists eventually.

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