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Methodology for Selecting the Appropriate Electric Motor for Robotic Modular Systems for Lower Extremities

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Abstract: Torque calculation is essential for selecting the appropriate motor to achieve the required torque at each joint of a hybrid exoskeleton. In recent years, the combined use of functional electrical stimulation (FES) and robotic devices, called hybrid robotic rehabilitation systems, has emerged as a promising approach for the rehabilitating of lower limb motor functions. Specifically, the implementation strategy of functional electrical stimulation walking aid combined with the design of the exoskeleton part is the main focus of our research team. This work copes with issues of the design process of a robotic exoskeleton. The importance of robotic exoskeletons for providing walking aid to people with mobility disorders or the elderly is discussed. Furthermore, the approaches to calculating the joint torques are investigated, and the mathematical models and parameters of interest are identified. This further includes the comparative data for servo motors: robotic exoskeleton characteristics and actuator analysis in the robotic exoskeleton. The aforementioned is used to propose a mathematical model based on previous models (Zatsiorsky BSP and Dempster BSP body segment parameters models, forward kinematics models), which was extended to include added adjustable parameters such as length, area, volume, mass, density, the centre of mass, human body characteristics, and considering both static and dynamic parameter extraction. Then, an analytic method is presented, exploiting the results from the mathematical model to select the appropriate motor for each joint of the lower extremities. The detailed description of the method is followed by examples, experimental measurements, and statistical analysis of qualitative and quantitative characteristics. The results showed deviations from typical calculation methods, offering a better understanding of the motor requirements for each joint of the exoskeleton and avoiding selections of marginal functionality features of the motors. In addition, researchers are offered a tool for replicating the results of this work, allowing them to configure the parameters associated with the servo motor features. The researcher can either use the embedded library developed for this work or enter new data into it, affecting the calculated torques of the model joints. The extracted results assist the researcher in choosing the appropriate motor among commercially available brushed and brushless motors based on the torques applied at each joint in robotic articulated systems.

Keywords: robotic exoskeletons; servo motor; brushless; brushed; actuators; torque; centre mass

Citation: Kavalieros, D.; Kapothanasis, E.; Kakarountas, A.; Loukopoulos, T. Methodology for Selecting the Appropriate Electric Motor for Robotic Modular Systems for Lower Extremities. *Healthcare* **2022**, *10*, 2054. https://doi.org/10.3390/healthcare10102054

Academic Editor: Daniele Giansanti

Received: 18 August 2022
Accepted: 9 October 2022
Published: 17 October 2022

1. Introduction

Lately, exoskeletons are designed to provide strength in gait and heavy transport loads. There are also designs for assisting people with disorders in motion or older adults. Gait rehabilitation is one of the most significant challenges for society in the coming years due to population ageing and the increase of diseases affecting motion. Partial or total paralysis of one side of the body due to injuries in the motor centres of the brain is called Hemiplegia. Hemiplegia is a disorder that causes one-half of the human body to fail to perform its functions. This disorder is caused mainly due to stroke, and in many cases, it is hereditary. Recovery from a stroke is complex, and the treatment is prolonged. Wearable robotics is an area that provides solutions for such problems. A wearable robot extends, complements, or empowers the human limb where it is worn. These kinds of robots are classified according to the function they perform:

- **Empowering robotic exoskeletons:** These kinds of robots are known as extenders since they extend the strength of the human hand beyond its natural ability while maintaining human control of the robot.
- **Orthotic robots:** An orthosis maps the anatomy of a limb to restore lost functions. The robotic counterpart of orthosis is robotic exoskeletons that complement the ability of the limbs. Exoskeletons are also capable of restoring handicapped functions.
- **Prosthetic robots:** These robots are devices that fully substitute lost limbs [1].

Figure 1 shows two examples of wearable robots. The scientific community differentiates exoskeletons from orthosis by defining the former as the devices that enhance the physical capabilities of wholesome users and the latter as the devices that assist persons with limb impairments [2]. Specifically, in Figure 1, the lower extremity of an orthotic exoskeleton for mobility problems is presented as developed by the authors, and the lower extremity of a prosthetic robot, according to work in [1], is presented in Figure 1b. Despite their differences, both devices act in parallel with the limb. In the medical field, in combination with rehabilitation therapies, exoskeletons can help patients with spinal cord injuries, strokes, and lower limb paralysis caused by hemiplegia [1].

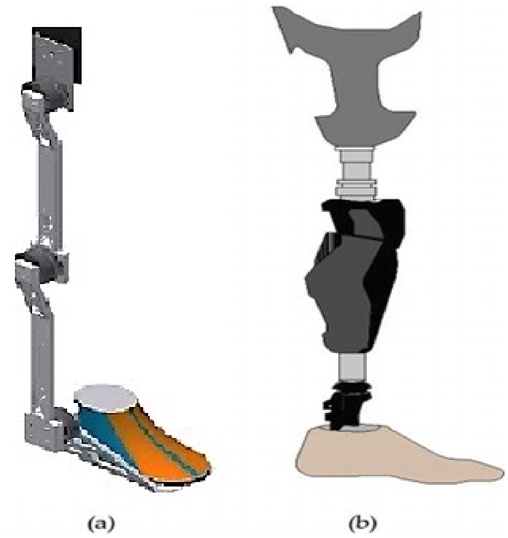

Figure 1. (**a**) Lower limb orthotic exoskeleton, (**b**) lower limb prosthetic robot [1].

The studies of the calculation of torque equations in each lower extremity exoskeleton joint were based on the kinematic analysis. Specifically, in [3], forward kinematics was applied to find the foot's position when values were given for the corners of the joint. The torque required on each joint is determined using free-body diagrams of different joints. The work found in [4] proposed the lower limb robotic exoskeletons (LLRE) model. The free-body diagram of force on the knees and hips was constructed. Dynamic hip and knee models were obtained, considering the hips and knees as support points. The torque equations of the lower limb joints were calculated according to the parameters of the specific model. Another approach to calculating the joint torques was also based on kinematics. The kinematic analysis is applied through forward and inverse kinematics as proposed in [1]. The Euler–Lagrange method is used to obtain the dynamic equations of the exoskeleton. The literature review was performed by querying the Google Scholar database. To identify papers on robotic lower limb exoskeletons, we mainly focused on electric actuation technologies. The results were filtered based on the officially used torque calculation models to determine the percentages. Nearly 600 scientific articles have been published in the last three years on robotic exoskeletons for the lower extremities based on kinematics (thus, excluding the upper extremities cases).