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Graduate School of Biomedical Engineering

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Exoskeleton Week 9 Draft Report

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BIOM1010
Engineering in Medicine and Biology

Exoskeleton
Week 9 Design Draft Report

2018 Semester 2

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Design

Function

Control System:

The types of control systems can be sorted into three general approaches [1]:

- the model-based control system is where the control system and processing are based on a physical model of the body. The approach is split into two main models:
  - The dynamic model allows the exoskeleton to be controlled by the user physically moving the skeleton
  - The muscle model uses electromyography as its primary input;
- the physical parameters-based control system: proportion-derivative controller, torque/force controller, and interaction force controllers can be combined into a full control circuit, and;
- the usage-based control system works by knowing the path the patient's limb must take, and actuates to correct the patient if they deviate from the desired path.

Mechanical System:

The simplest and most effective way to actuate an exoskeleton is to use what regular robots use: high-torque servo motors, stepper motors, linear actuators, and hydraulic cylinders [2]. Although novel technologies can still be used such as pneumatic air muscles.

The motion of the human body must be taken into account when designing a mechanical system for movement. The system should never be designed to normally move beyond a human's natural range of movement, as this may cause injury. Human joints are difficult to design around, such as the shoulder, which has many degrees of freedom in movement.

System Example

Figure 1 - Rewalk Exoskeleton (Source: https://exoskeletonreport.com/product/rewalk/)

The ReWalk *(figure 1)* uses a combination of sensors and control systems that allow individuals with gait disability to mobilise. Sensors are placed near the lower chest as a control method. If the user leans forward, the walking program activates.

The device has a patient control system which allows the patient to select an operating mode such as sit, stand, or walk. From these commands, the device adjusts its algorithms and control methods in order to carry out the action. Sensors all around the device assist with stability in response to external stimulus. While the device is not an *intuitive* or natural replacement for the user's legs, it allows independent mobility and therefore increases the quality of life.

Materials

The material of the exoskeleton frame should have *"low density, high strength and toughness"* [3]. Exoskeletons are typically made of rigid materials such as steel, carbon fibre, or alloys due to their properties as listed in table 1.

Table 1 - Exoskeleton Materials

Material	***Property***
Steel	○ High Density $(8\ kg/dm^3)$ ○ Cheap $(\$1,091/t)$ ○ Rigid
Carbon Fibre	○ Rigid ○ High Specific Strength $(2457\ kN \cdot m/kg)$ ○ High Tensile Strength $(3.5\ GPa)$ ○ Corrosion Resistant ○ Biologically Inert ○ Expensive $(\$22,000/t)$ ○ Low Density ($1.75 - 2.06 kg/dm^3$)
Duralumin	○ Rigid ○ Lightweight $(2.79\ kg/dm^3)$ ○ Corrosion Resistant ○ Cheap $(\$2,000 - 3,000/t)$ ○ High Tensile Strength $(505\ MPa)$

Steel is cheaper but relatively heavy. A heavier exoskeleton requires more power and can be uncomfortable for the user.

Carbon fibre is the most attractive material for exoskeleton frames due to its high strength to weight ratio (specific strength), rigidity, resistance to corrosion and biological inertness. Therefore exoskeleton frames are biocompatible, small in size and light yet strong enough to support the weight of the user. However, carbon fibre is expensive to manufacture which increases patient costs.[4]

Duralumin (aluminium-copper alloy) is cheaper, heavier and has a lower tensile strength than carbon fibre. By a simulation of applying an average human weight force of 800 N to the material. The resulting stress was 88.55 MPa [5]. Therefore, duralumin may be a more suitable exoskeleton material.

Distinguishing Features

Exoskeletons for gait assistance have distinguishing features that allow its comparison to wheelchairs which have long been the golden standard for mobility in individuals with gait disability [6] *(refer to table 2)*.

Table 2 - List of Features of Exoskeletons and Wheelchairs

Exoskeleton Design Features	***Wheelchair Design Features***
○ Use of sensors to activate movement ○ Walking process is automatic ○ Modes for walking, sitting, standing and changing positions ○ Joints in exoskeleton to reflect joints in human anatomy ○ Requires battery backpack (ReWalk model lasts 4 hours continuously and 8 hours intermittently)	○ Manual wheelchairs are wheeled by hand or pushed (requires manpower) ○ Power wheelchairs are joystick controlled ○ Seat with independent wheels to each side ○ Power wheelchairs require a battery (80-96.5 km per charge)

Exoskeleton design features such as sensors, automated walking, joints, modes and battery supply; address gait disability by mimicking normal human walking. This differs significantly from the wheelchair's design features of utilising the wheel and a seat to overcome gait disability.

References

1. Anam K, Al-Jumaily A. Active Exoskeleton Control Systems: State of the Art. Procedia Engineering [Internet]. 2012 [cited 20 September 2018];41:988-994. Available from: https://www.sciencedirect.com/science/article/pii/S1877705812026732

   The paper acknowledges that exoskeleton control systems have had less coverage than the mechanical aspects. It attempts to provide a comprehensive overview of the methods used on the input side of such a device and was therefore a useful resource. Because it is so comprehensive, many of the concepts are relatively abstract and difficult to follow without some knowledge of the many provided example exoskeletons and the details of their novel control systems.

2. REWALK ROBOTICS LTD. Motorized exoskeleton unit. USA; US20130253385A1, 2013.

   This patent consists of an in-depth outline of the features of a concept for the ReWalk exoskeleton for gait assistance. This patent was referenced because it provided broad insight into the mechanical systems and components of the exoskeleton outlined in the report. Being only a patent, the purpose was to guard intellectual property while allowing for future design choices to be made.

3. Rupal B, Rafique S, Singla A, Singla E, Isaksson M, Virk G. Lower-limb exoskeletons. International Journal of Advanced Robotic Systems [Internet]. 2017 [cited 21 September 2018];14(6):172988141774355. Available from: http://journals.sagepub.com/doi/full/10.1177/1729881417743554

   This journal article analyses the design of exoskeletons in terms of mechanical and electrical systems with reference to its materials and components. It covers current and future developments as well as issues surrounding gait disabilities. It also provides some insight into potential medical but non-rehabilitative applications such as mobility for the elderly. This reference was used for the design and materials section of the report.

4. Gardiner G. Composites in exoskeletons [Internet]. CompositesWorld. 2016 [cited 20 September 2018]. Available from: https://www.compositesworld.com/blog/post/composites-in-exoskeletons

   This article is a blog post on material composites used in exoskeletons. This was referenced in the materials section of the report due to the detailed review of exoskeleton frame materials and discussion of future developments of materials. It also provides some insight into the advantages and disadvantages of carbon fibre as a structural material.

5. Kim J, Han J, Kim D, Baek Y. Design of a Walking Assistance Lower Limb Exoskeleton for Paraplegic Patients and Hardware Validation Using CoP. International Journal of Advanced Robotic Systems [Internet]. 2013;10(2):113. Available from: http://journals.sagepub.com/doi/10.5772/55336

   This journal discusses the design process of a particular exoskeleton for gait assistance where the purpose of particular features, materials and functions for this exoskeleton were referenced in the draft report. This is because the design process displayed good examples of what an exoskeleton for gait assistance should have. It also documented and provided specifications for the material duralumin demonstrating its viability for use in exoskeletons.

6. Lajeunesse V, Vincent C, Routhier F, Careau E, Michaud F. Exoskeletons' design and usefulness evidence according to a systematic review of lower limb exoskeletons used for functional mobility by people with spinal cord injury. Disability and Rehabilitation: Assistive Technology. 2015;11(7):535-547.

   This article is a study and systematic review on a range of commercial exoskeletons, their specifications and effectiveness as gait assist devices. The authors were not confident in the findings of their study, as, being such a cutting-edge technology, there has been very little research into the community impact of exoskeletons.