Learning from the nature: Bionics & Lightweight design

Jorge Rolando Alvarez Tello
Universidad Politécnica de Catalunya (Barcelona Tech)
Barcelona, Spain
jorge.rolando.alvarez@estudiant.upc.edu

Abstract: The integration of the systems will be an asset to support the treatment of the paralysis disease of Duchenne in Ecuador. The task has a high social impact to perform in cost reductions and user experience, so as the co-working to achieve the solution for the construction of a low cost "Bioexoskeleton". This lightweight structure is bionic inspired and autonomous robotized with an easy recyclability of the materials and design concepts like the bamboo and the spider web between others. The solution to this disease will be provided for the robotic design of the exoskeleton optimized with biomechanics design and concepts of the bionic and biomimetic. The concept phase of the process design needs the inverse engineering of the lightweight structures based on insects or arthropods performing with the FEM and the research for the characterization of the biomaterials for the modelling and construction. That will be also a low cost product that permit the evaluation and validation of the method applied. The possibility to expand the analogy of the solution for problems of others research fields or complement the current research lines is open. This is a part of the evolution for the future in a cybernetic culture.

***Keywords*:** Bionics, biomechanics, lightweight, Duchenne (DMD), FEM

INTRODUCTION

Actually, the most important problems in the world are the management and store of resources, energy and information. As application for the solution with the bionics and the lightweight design, it proposed the DMD assistive orthoses development in Ecuador. The task has a high social impact to perform in cost reductions and user experience, so as the co-working to achieve the solution with the application for the construction of a low cost "Bioexoskeleton". This lightweight structure is autonomous robotized with an easy recyclability of the materials like the bamboo and the model according to the spider web.

With approximately 20 to 30 in every 100.000 born males attributed genetic disorder during the last decade with reference at year 2013, Duchenne muscular dystrophy is an X linked recessive genetic disorder caused by mutations in the dystrophin gene (DMD) that affect at the male population according to the Public Health Ministry of Ecuador [1]. This disease was discovered in 1986 but nowadays there is not a cure. The patients with this disease loose the Autonomy of the body while they are growing without a support for a whole mobility and autonomy. There are wheelchairs, walkers or aluminium crutches to supply partially this autonomy but these are limited mechanism. Actually, the technology integrates in the wheelchairs a motorized system for the mobility, but with the accessibility limited at the fitting of the infrastructure of the building or fields to transit. With the robotic integration, there is an exoskeleton (assistive orthoses) developed with lightweight modules based in material with special mechanical and structural properties (stiffness, hardness, bending, weight, etc.). These materials are obtained thought complex and expensive cost and mostly the development is according to specification form the military defence or aerospace sectors, as well as in the industry [8], [9].

METHODOLOGY

In this extended abstract the design and pilot validation of a skeleton with biomaterials or biodesigned inspired, is proposal. There are in the market a few skeleton models to innovate them with new materials and the assessment of the model optimization (Figure 1). The development is covering the design (inverse engineering), materials properties and the FEM optimization to finish the virtual prototyping phase. All alternatives analysed are the input to develop a low cost Bioskeleton.

Figure 1: Picture of a typical indigo exoskeleton [3]

Biomechanics of the Bioskeleton

The structure design must be adapted to the material geometry requirements from the characterization of natural sources as bamboo for the thigh or arms and the mechanical joints design with a coconut shell.
Freedom of motion is accomplished by mechanical joints, which are nearly aligned with the human joints. The system compensates for the thigh and arm weight, using elastic bands for static balance, in every position of the thigh or arm respectively. As opposed to existing devices, the proposed kinematic structure allows trunk motion and requires fewer links and less joint space without compromising balancing precision (Figure 2). To get a functional prototype, it must be validated in ten DMD patients, using 3D motion analysis [2]. The concept of the spider web for the flexibility and adjustment of the exoskeleton modules must be developed and optimized [7].

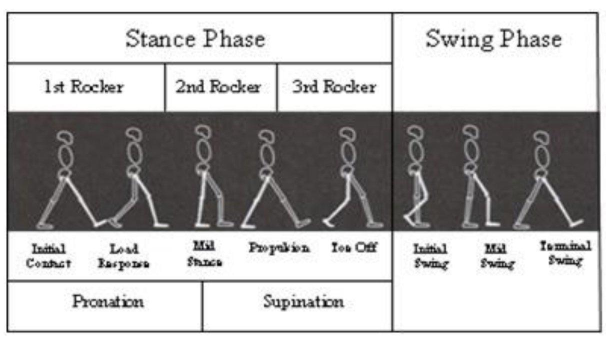

Figure 2: Schematic of normal human walking in human (Stance and Swing phases) [3].

FEM Optimization

For the selection of the material, it must be mechanical tested to determine the strength, stiffness, bending, deformation, natural frequency, etc.; under temperature conditions in RT and between -20ºC and 100 ºC, to get the material properties for the FEM-simulation [4]. With the values is possible to fulfil the parameterization and the boundary condition for the FEM simulation of the axisymmetric composite [3], [8], [9] as an important consideration that arises when computing effective properties of composite materials is the effect of the specimen scale with respect to the scale of the unit cell [8] (**Table 1**).

Table 1: Material properties requirement [4]

Material Property	Symbol
Tensile Modulus	E_{11}, $E_{22}=E_{33}$
Poisson´s ratio	$v_{12}= v_{13}$, v_{23}
Shear modulus	$G_{12}=G_{13}$, $G_{23} = E_{22}/(2*(1+ v_{23}))$
Secant-intercept modulus	$K_{12}=K_{13}$, $K_{23} = K_{12}*G_{23}/G_{12}$
Exponent	n
Transverse tensile strength	Y^T
Shear strength	S^L

The FEM obtains the correct solution for any FE model by minimizing the energy functional [5], [6]. The minimum of the functional is found by setting the derivative of the functional with respect to the unknown grid point potential for zero. Thus, the basic equation for FE analysis is:

$$\frac{\partial F}{\partial p} = 0 \quad \text{Equation 1}$$

Where F is the energy functional and p is the unknown grid point potential (in mechanics, the potential is displacement.) to be calculated (Figure 3).

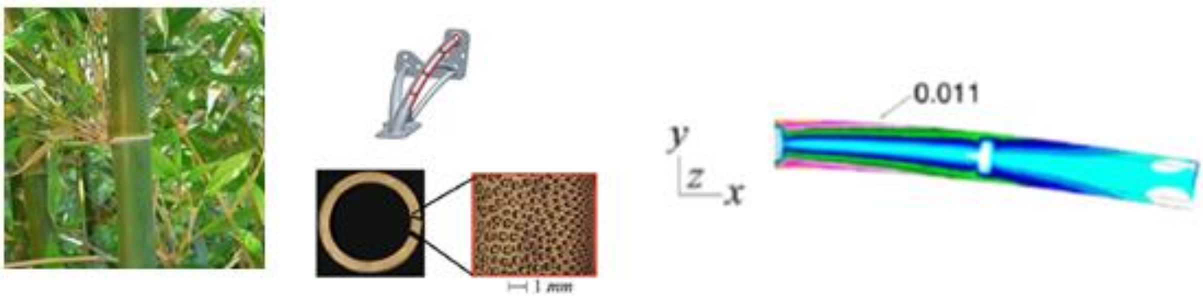

Figure 3: FEM simulation of the bamboo

Cost

For more information in the design of the Bioskeleton it will be in assessment more biomaterials or biostructures. In this way it is possible to reduce the cost for the manufacturing of the exoskeleton as a Bioskeleton with low cost materials [3] (Table 2).

Table 2: Benchmarking of the exoskeleton at 28/12/2016

Manufacturer	Exoskeleton model	Exoskeleton Materials	Cost [$]	Weight [kg]
Cyberdyne Inc.	HAL-5	Ni, Mo and duralumin	14.000-19.000	65-80
ReWalk Robotics	ReWalk Personal 6.0	Duraluminium	70.000	~ 80
---	Bioexoskeleton	Biomaterials & Al	expected: 8.000	80

FINDINGS

The design of the exoskeleton is incurring in complexes methods, which increase the cost of the manufacturing with expensive materials and processes. With the analysis of the kinematic in the biomechanics, the inverse engineering of the prototype is modelled and optimized. The materials properties are characterised as homogenous orthotropic medium [8] with a low E module in the transversal axes. The model is characterised with bars of bamboo as a naturally graded fiber-composite

[8]. To get an accessible support for this disease and to ensure the mechanical and structural properties for a new model of exoskeleton, it is started an analysis to integrate new recycling biomaterials with a lower environmental impact to give accessibility until the disease DMD research develop a cure. The typical yield strength is 130 MPa for the Aluminium alloy with a variation according the alloys elements, for the consideration of the replacement, the biomaterial must be around this value **(**Table 3**)**

Table 3: Mechanical properties comparison

Material	Tensile Strength σ [MPa]	Young´s modulus E [GPa]	Density [g/cm^3]
Aluminium EN-AW 6060	120	70	2.7
Bamboo	42	11-17	0.6 - 1.1

CONCLUSIONS

The extended abstract was focused on assessing the natural materials as biomaterials to be a proposal for the replacing of metals that increase the cost of the manufacturing of the exoskeleton for the support of the Paralysis of Duchenne with the current material used in exoskeleton design. Although not all biomaterials satisfied the yield strength requirements the bamboo can be used as replacement material for duralumin. Additional characteristics of bending and toughness make bamboo a more favourable replacement material for the design of exoskeleton. In the design the lightweight structure of the spider web bring the support for the energy supply and the subjection bands of the exoskeleton. . With the evaluations of the replace of natural materials at the current used in the construction of the exoskeleton, the development of the new concepts of Exoskeleton with biomaterials, or called Bioexoskeleton, there is the possibility to get a low cost exoskeleton to get a facility to support the paralysis Duchenne.

For the developing of new structures with biomaterials, the exoskeleton or "Bioskeleton" must be designed and optimized with new algorithms for the modelling and the scalability of the systems.

REFERENCES

1. Paola Cristina Montenegro Larrea , " Identification of deletions and duplications in Ecuadorian patients with Duchenne Muscular Dystrophy", (MSc. diss., The University of Nottingham, 2013)
2. J Neuroeng Rehabil, Design and pilot validation of A-gear: a novel wearable dynamic arm support, 2015, doi: 10.1186/s12984-015-0072-y
3. Reed KS, Kalu PN, An Assessment of Bamboo as a Potential. Low-Cost Material for Exoskeleton Design in Normal Walking, 2016
4. Yuri Nikishkov, Andrew Makeev, and Guillaume Seon, Finite Element-Based Simulations of Damage in Composites, 2009, American Helicopter Society 65th Annual Forum
5. Tankut, Tankut, Zor, Finite Element Analysis of Wood Material, 2014, doi: 10.5552/drind.2014.1254
6. Zhang, Haohan, "Design of a Passive Exoskeleton Spine" (2014).Masters Theses May 2014 - current. Paper 123.
7. ADAM ZOSS and H. KAZEROONI, Design of an electrically actuated lower extremity Exoskeleton, 2006
8. Emilio Carlos Nelli Silva"", Matthew C. Walters" and Glaucio H. Paulino", Modeling Bamboo as a Functionally Graded Material, 2009
9. Zhao Yanjun, Zhang Wanqing, and Ge Wenqing, Li Shuguang, Finite Element Simulation of Soldier Lower Extremity Exoskeleton, 2013