2014 5th IEEE RAS & EMBS International Conference on
Biomedical Robotics and Biomechatronics (BioRob)
August 12-15, 2014. São Paulo, Brazil

Knee Torque Analysis to Implement an Exoskeleton

María Augusta Flores Rivera, Bertha Catalina Punin Sigcha, Pedro Alcibiades Jara Maldonado, Luis Fernando Fernandez, Patricio Fernando Urgiles Ortiz, Patricio Javier Guaraca Medina, Student Member, IEEE, Luis Alfredo Calle Arevalo, Student Member, IEEE.
Grupo de Investigación en Ingeniería Biomédica (GIIB)-Universidad Politécnica Salesiana
Cuenca-Ecuador

***Abstract*—This document presents a mathematical and experimental analysis by the Lagrange equations and with a electrogoniometer, which allows us to obtain the trajectories realized by the knee, by the angular displacing between: hip, knee and ankle; with this and applying mathematical concepts, it is possible to determine the torque applied to the knee while getting up.**

***Index Terms*—Electrogoniometer, Inertia, Lagrange, Exoskeleton, Sagittal Plane, Knee.**

I. INTRODUCTION

The knee joint is the largest joint and superficial, hinge type, in which the movements are a combination of sliding, rolling and rotating on the vertical axis [18].

The movements made by this joint depend on the femur and the tibia, which controls the elongation and shortening of the lower extremity; thus, the main movements are flexion and extension, with a degree of rotation [19].

Also, the changes caused by the activity realized by a person, the knee joint remains stable because of the integration of the articular geometry, the soft white foil weave's restrictions and loads applied to the articulation through muscular action and the supporting point which holds the weight [20].

María Augusta Flores Rivera: Student of Electronic Engineering, Universidad Politécnica Salesiana Sede Cuenca (e-mail: mfloresr@est.ups.edu.ec).
Bertha Catalina Punín Sigcha: Student of Electronic Engineering, Universidad Politécnica Salesiana Sede Cuenca (e-mail: bpunin@est.ups.edu.ec).
Pedro Alcibiades Jara Maldonado: Student of Electronic Engineering, Universidad Politécnica Salesiana Sede Cuenca (e-mail: pjaram@est.ups.edu.ec).
Luis Fernando Fernandez: Student of Electronic Engineering, Universidad Politécnica Salesiana Sede Cuenca (e-mail: pjaram@est.ups.edu.ec).
Patricio Fernando Urgiles Ortiz: Professor of Electronic Engineering, Universidad Politécnica Salesiana Sede Cuenca (corresponding author to provide phone: 2862213 ext: 1199, e-mail: furgiles@est.ups.edu.ec).
Patricio Javier Guaraca Medina: Student of Electronic Engineering, member of GIIB (Grupo de Investigación en Ingeniería Biomédica), Universidad Politécnica Salesiana Sede Cuenca, IEEE Student Member (e-mail: patricio_guaraca@ieee.org).
Luis Alfredo Calle Arevalo: Student of Electronic Engineering, member of GIIB (Grupo de Investigación en Ingeniería Biomédica), Universidad Politécnica Salesiana Sede Cuenca, IEEE Student Member (e-mail: luisalfredo@ieee.org).

II. ART STATE

A. Knee

The knee is a joint formed by the junction of the lower end of the femur, upper tibia and patella, this kind of synovial, consisting of two functionally different structural joints and complement each other: the tibiofemoral joint and patellofemoral [2,3].

B. Sagittal Plane's Analysis

Analysis in the sagittal plane of motion of the knee. The knee flexion and extension are realized on the minor axis in the sagittal plane. The maximum movements reach their maximum value at 90 ° when the hip is flexed [4]. To consider the possible movements of the knee, we have the following kinematic diagram in the Figure 1.

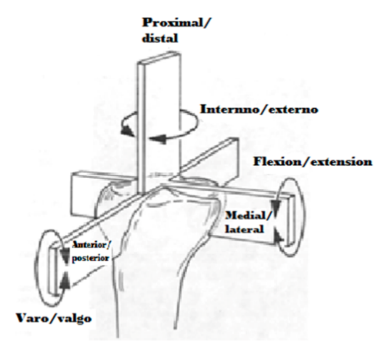

Figure 1. Representative scheme of the knees's freedom degrees [5]

C. Principles of Biomechanics

From the Biomechanics' view point, the knee performs load transmission, conservation of momentum, and provides a pair of suitable strength. This joint is one of the longest arms lever body, it supports high forces and thereby, it's more susceptible to injury. [6, 7].

D. Hip

It consists of two bones called iliac and innominate, their movements are made in the minor axis of flexion-extension,

978-1-4799-3127-9/6/14/$31.00 ©2014 IEEE

Figure 2. Experiment using the electrogoniometer for obtaining trajectories

it was performed in the anteroposterior axis of the sagittal plane, then the movements of abduction-adduction are made and finally the movements of external rotation and internal rotation develops in the vertical axis. [17]

E. Data acquisition of the signals

An electrogoniometer was used for the trajectories acquisition that the knee, hip and ankle perform. This acquisition was realized by using different positions listed below.

1) Position 1: Figure 3 shows that the individual is sitting and his torso has an orthogonal angle to the thigh $\theta = 90^o$and his legs are bent at an angle θ of 70^o approximately, in order to maintain balance while lifting.

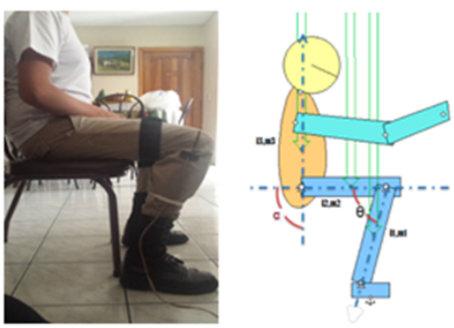

Figure 3. Experiment scheme, position number one obtain trajectories

Figure 4 shows the trajectory obtained from the position 1.

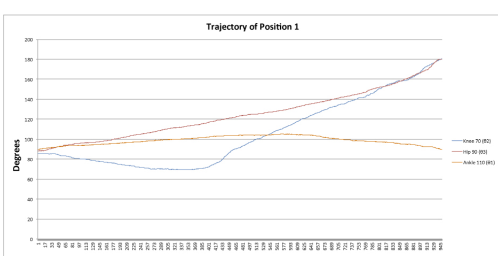

Figure 4. Data obtained from the path of the knee in the first position

2) Position 2: Figure 5 shows that the individual is sitting with the torso inclined at an angle of $\theta = 70^o$ And relative to the thigh with the leg, it is at an angle of $\theta = 90^o$.

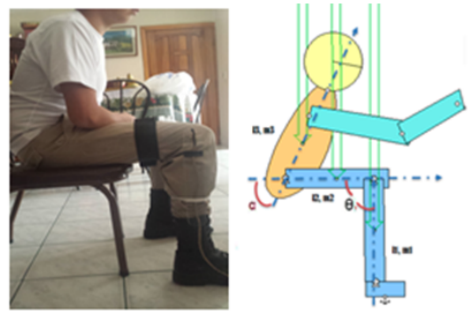

Figure 5. Experiment scheme, position number two obtain trajectories

Figure 6 shows the trajectory obtained from the position 2.

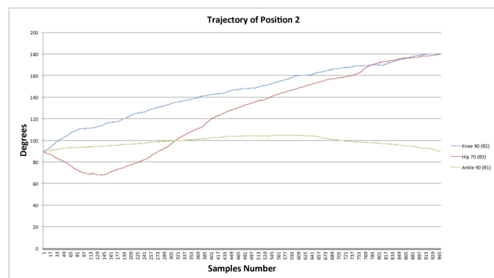

Figure 6. Data obtained from the path of the knee in the second position

3) Position 3: Figure 7 shows that the individual is sitting with the torso inclined at an angle of $\theta = 80^o$ Relative to the thigh and leg, it is at an angle $\theta = 80^o$.

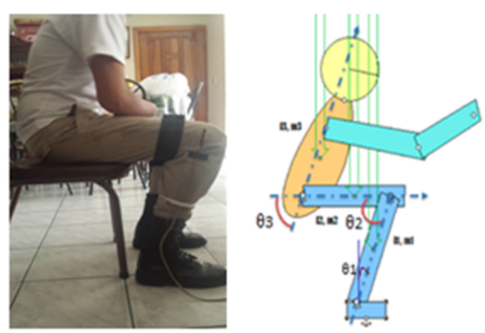

Figure 7. Experimental scheme, position number three for obtaining trajectories

Figure 8 shows the trajectory obtained from the position 3.

Figure 8. Data obtained from the path of the knee in the third position

BODY PARTS	PERCENTAGE	WEIGHT (kg)	WEIGHT (N)
Trunk without member	50	25	245.25
Hand	0.7	0.35	3.4335
Bench Hand	2.3	1.15	11.2815
Bench without Hand	1.6	0.8	7.848
Upper Arm	2.7	1.35	13.2435
Full Arm	5	2.5	24.525
Foot	1.5	0.75	7.3575
Inside Leg with Foot	5.9	2.95	28.9395
Inside Leg without the Foot	4.4	2.2 2	1.582
Thigh	10.1	5.05	49.5405
Full Leg	16	8	78.48

Table I
WEIGHTS FOR EACH OF THE INDIVIDUAL MODEL

III. MATHEMATICAL ANALYSIS OF TORQUE

The analysis is performed by applying torques at three links, as shown in Figure 9. Here, we try to find the joint torques of ankle, knee and hip. Lagrange equations are consider as a mathematical method, which analyzes the system with the three links with their distances, masses and angles.

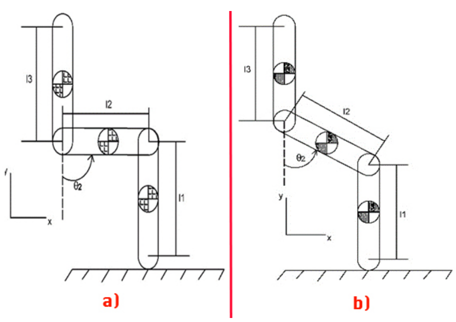

Figure 9. Representation of the kinematic model through links

Using Figure 10 we obtain the distances of each part of the body of an individual of 1.55m and 50 kg.

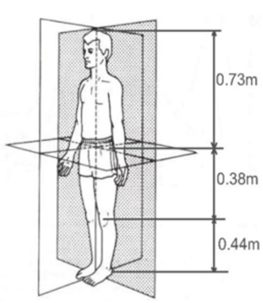

Figure 10. Distances between the various joints of the human body of the individual model [3]

In Table 1, we can observe the weights of each individual part of the body.

Now, the following is to estimate the values of each link (Table 2) where we can say that link 3 should have the greatest weight since it covers more parts. All of this is based on Table 1 of the distribution of weights:

# Link	body parts	Total mass
1	Part 8 (2)	M1=5.9 kg
2	Part 10 (2)	M2=10.1 kg
3	Parts: 1 y 6(2)	M3=34 kg

Table II
BODIES OF THE LINKS

According to Figure 10, the distance between joints of the human body can be see at (Table 3):

#Link	Distance
1 (calf)	L1=0.44m
2 (thigh)	L2=0.38m
3 (trunk + arms)	L3=0.73m

Table III
DISTANCES OF THE LINKS

The objective of Lagrange equations is to find the kinetic energy and potential energy, and then apply the Lagrangian and finally apply the derived as compared to θ_i angle or at time t.

$$\frac{d}{dt}\left(\frac{\partial L}{\partial_l^i}\right) - \left(\frac{\partial L}{\partial \theta_i}\right) = \tau \tag{1}$$

A. Position Components

Each link requires to find the position coordinates of the center of mass.

$$x_3 = l_3 sen\left(\theta_3\right) \tag{2}$$

$$y_3 = -l_3 sen\left(\theta_3\right) \tag{3}$$

$$x_2 = l_3 sen\left(\theta_3\right) + l_2 sen\left(\theta_2\right) \tag{4}$$

$$y_2 = -l_3 sen\left(\theta_3\right) - l_2 sen\left(\theta_2\right) \tag{5}$$

$$x_1 = l_3 sen\left(\theta_3\right) + l_2 sen\left(\theta_2\right) + l_1 sen\left(\theta_1\right) \tag{6}$$

$$y_1 = -l_3 sen\left(\theta_3\right) - l_2 sen\left(\theta_2\right) - l_1 sen\left(\theta_1\right) \tag{7}$$

B. Velocity Components

Velocity is the derived of position so each component is derived in "x" and "y".

$$\dot{x_3} = l_3\dot{\theta}_3 cos(\theta_3) \tag{8}$$

$$\dot{y_3} = l_3\dot{\theta}_3 cos(\theta_3) \tag{9}$$

$$v_3^2 = \left(\dot{x_3^2} + \dot{y_3^2}\right) \tag{10}$$

$$v_3^2 = l_3^2\dot{\theta_3^2} cos^2(\theta_3) + l_3^2\dot{\theta_3^2} sen^2(\theta_3) \tag{11}$$

Applying the trigonometric identity:

$$cos^2\phi + sen^2\phi = 1 \tag{12}$$

$$v_3^2 = l_3^2\dot{\theta_3^2} \tag{13}$$

$$\dot{x_2} = l_3\dot{\theta}_3 cos(\theta_3) + l_2\dot{\theta}_2 cos(\theta_2) \tag{14}$$

$$\dot{y_2} = l_3\dot{\theta}_3 sen(\theta_3) + l_2\dot{\theta}_2 sen(\theta_2) \tag{15}$$

$$v_2^2 = \left(\dot{x_2^2} + \dot{y_2^2}\right) \tag{16}$$

Applying trigonometric identities:

$$cos(\phi - \psi) = cos\phi cos\psi + sen\phi sen\psi \tag{17}$$

$$v_2^2 = \{l_3^2\dot{\theta_3^2} + l_2^2\dot{\theta_2^2} + 2l_3l_2\dot{\theta}_3\dot{\theta}_2 cos(\theta_3 + \theta_2)\} \tag{18}$$

$$\dot{x_1} = l_3\dot{\theta}_3 cos(\theta_3) + l_2\dot{\theta}_2 cos(\theta_2) + l_1\dot{\theta}_1 cos(\theta_2) \tag{19}$$

$$\dot{y_1} = l_3\dot{\theta}_3 sen(\theta_3) + l_2\dot{\theta}_2 sen(\theta_2) + l_1\dot{\theta}_1 sen(\theta_2) \tag{20}$$

$$v_1^2 = \left(\dot{x_1^2} + \dot{y_1^2}\right) \tag{21}$$

$$v_1^2 = \{l_3^2\dot{\theta_3^2} + l_2^2\dot{\theta_2^2} + 2l_3l_2\dot{\theta}_3\dot{\theta}_2 cos(\theta_3 - \theta_2) + \tag{22}$$

$$+2l_3l_1\dot{\theta}_3\dot{\theta}_1 cos(\theta_3 - \theta_1) + 2l_2l_1\dot{\theta}_2\dot{\theta}_1 cos(\theta_2 - \theta_1)\}$$

For each kinetic energy we use the following equation:

$$T = T_1 + T_2 + T_3 \tag{23}$$

$$T_1 = \frac{1}{2}m_1v_1^2, T_2 = \frac{1}{2}m_2v_2^2, T_3 = \frac{1}{2}m_3v_3^2 \tag{24}$$

$$T = \frac{1}{2}m_1l_3^2\dot{\theta_3^2} + \frac{1}{2}m_2[l_3^2\dot{\theta_3^2} + l_3^2 + \dot{\theta_2^2} +$$

$$+2l_3l_2\dot{\theta}_3\dot{\theta}_2 cos(\theta_3 - \theta_2) + \frac{1}{2}m_3[l_3^2\dot{\theta_3^2} +$$

$$+l_2^2\dot{\theta_2^2} + l_1^2\theta_1^2 \dot{+} 2l_3l_2\dot{\theta}_3\dot{\theta}_2 cos(\theta_3 - \theta_2) +$$

$$+2l_3l_1\dot{\theta}_3\dot{\theta}_1 cos(\theta_3 - \theta_1) + 2l_2l_1\dot{\theta}_2\dot{\theta}_1 cos(\theta_2 - \theta_1)] \tag{25}$$

C. Potential Energy

The formula for the potential energy of each link is given as follows:

$$V_1 = m_1gy_1, V_2 = m_2gy_2, V_3 = m_3gy_3 \tag{26}$$

Thus the total potential energy of the system is:

$$V = V_1 + V_2 + V_3 \tag{27}$$

$$V = m_3gl_3cos\theta_3 - m_2gl_3cos\theta_3 - m_2gl_2cos\theta_2 -$$

$$-m_1gl_3cos\theta_3 - m_1gl_2cos\theta_2 - m_1gl_1cos\theta_1 \tag{28}$$

The procedure to obtain the Lagrangian

$$L = T - V \tag{29}$$

$$L = \frac{1}{2}m_1l_3\dot{\theta}_3^2 + \frac{1}{2}m_2[l_3^2\dot{\theta}_3^2 + l_2^2 + \dot{\theta}_2^2 +$$

$$+2l_3l_2\dot{\theta}_3\dot{\theta}_2 cos(\theta_3 - \theta_2)] + \frac{1}{2}m_3 \cos[l_3^2\dot{\theta}_3^2 + l_2^2\dot{\theta}_2^2 +$$

$$+l_1^2\dot{\theta}_1^2 + 2l_3l_2\dot{\theta}_3\dot{\theta}_2 cos(\theta_3 - \theta_2) + 2l_3l_1\dot{\theta}_3\dot{\theta}_1 cos(\theta_3 - \theta_1) +$$

$$+2l_2l_1\dot{\theta}_2\dot{\theta}_1 cos(\theta_2 - \theta_1) + m_3gl_3\cos\theta_3 + m_2gl_3\cos +$$

$$+\theta_3 + m_2gl_2\cos\theta_2 + m_1gl_3\cos\theta_3 + m_1gl_2\cos\theta_2 +$$

$$+m_1gl_1\cos\theta_1] \tag{30}$$

Developing terms for τ_2

$$\frac{\delta L}{\delta\dot{\theta}_2} = \frac{1}{2}m_2[2\dot{\theta}_2 + 2l_3l_2\dot{\theta}_3\cos(\theta_3 - \theta_2)] +$$

$$+\frac{1}{2}m_3[2l_2^2\dot{\theta}_2 + 2l_3l_2\dot{\theta}_3\dot{\theta}_2\cos(\theta_3 - \theta_2) +$$

$$+2l_2l_3\dot{\theta}_1\cos(\theta_2 - \theta_1)] \tag{31}$$

Simplifying we obtain:

$$\frac{\delta L}{\delta\theta_2} = -m_2l_3l_2\dot{\theta}_3\dot{\theta}_2\sin(\theta_3 - \theta_2) -$$

$$-m_3 l_3 l_2 \dot{\theta}_3 \dot{\theta}_2 \sin(\theta_3 - \theta_2) - m_3 l_2 l_1 \dot{\theta}_2 \dot{\theta}_1 \sin(\theta_2 - \theta_1) -$$

$$-m_2 g l_2 \sin(\theta_2) - m_1 g l_2 \sin(\theta_2) \qquad (32)$$

Replacing all the terms obtained by the LaGrange equation for the knee torque we get:

$$\tau_2 = m_2[\ddot{\theta}_2 - l_3 l_2 \dot{\theta}_3 \cos(\dot{\theta}_3 - \dot{\theta}_2) \sin(\theta_3 - \theta_2)$$

$$+ l_3 l_2 \ddot{\theta}_3 \cos(\theta_3 - \theta_2)] + + m_3 l_2[-l_2 \ddot{\theta}_2 +$$

$$+ l_3 \dot{\theta}_3 \dot{\theta}_2 (\dot{\theta}_3 - \dot{\theta}_2) \sin(\theta_3 - \theta_2) + l_3 \ddot{\theta}_3 \ddot{\theta}_2 \cos(\theta_3 - \theta_2) -$$

$$- l_3 \dot{\theta}_1 (\dot{\theta}_2 - \dot{\theta}_1) \sin(\theta_2 - \theta_1) + l_3 \dot{\theta}_1 \cos(\theta_2 - \theta_1)] +$$

$$+ m_2 l_3 l_2 \dot{\theta}_3 \dot{\theta}_2 \sin(\theta_3 - \theta_2) + m_3 l_3 l_2 \dot{\theta}_3 \dot{\theta}_2 \sin(\theta_3 - \theta_2) +$$

$$+ m_3 l_2 l_1 \dot{\theta}_2 \dot{\theta}_1 \sin(\theta_2 - \theta_1) + m_2 g l_2 \sin(\theta_2)$$

$$+ m_1 g l_2 \sin(\theta_2) \qquad (33)$$

By polynomial interpolation method we obtain the following equations for each articulation of the lower limb is obtained.

- Theta3 hip

$$F(\vartheta_3) = \frac{(a + c\vartheta + w\vartheta^2 + g\vartheta^3 + k\vartheta^4)}{(1 + b\vartheta + d\vartheta^2 + f\vartheta^3 + h\vartheta^4 + l\vartheta^5)} \qquad (34)$$

$$a = 91.07; b = -0.99; c = -203.64; d = -13.27$$

$$w = -444.85; f = 33.94; g = 991.93$$

$$h = -16.82; k = 1024.03; l = 5.57$$

- Theta2 knee

$$F(\vartheta_2) = \frac{(a + c\vartheta + w\vartheta^2 + g\vartheta^3 + k\vartheta^4)}{(1 + b\vartheta + d\vartheta^2 + f\vartheta^3 + h\vartheta^4 + l\vartheta^5)} \qquad (35)$$

$$a = 90.07; b = -0.99; c = -203.64; d = -13.27$$

$$w = -444.85; f = 33.94; g = 991.93$$

$$h = -16.82; k = 1024.03; l = 5.70$$

- Theta1 ankle

$$F(\vartheta_1) = \frac{(a + c\vartheta^2 + w\vartheta^4 + g\vartheta^6 + k\vartheta^8 + n\vartheta^{10})}{(1 + b\vartheta^2 + d\vartheta^4 + f\vartheta^6 + h\vartheta^8 + l\vartheta^{10})} \qquad (36)$$

$$a = 90.207889; b = -7.3435681; c = -669.59399$$

$$d = 28.838203; w = 2645.5393$$

$$f = -7.1251034; g = -439.39567; h = -7.9180465$$

$$k = -850.74133; l = 3.3537797; n = 321.52812$$

Using equations 34, 35, 36 by a matlab script, the following graphs of the angular displacement of each joint are obtained as shown in Figure 11.

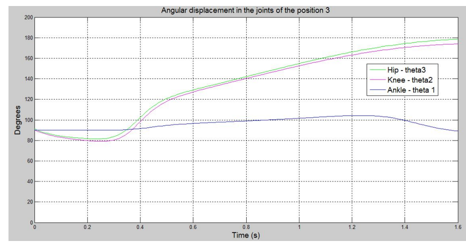

Figure 11. Angular displacement of the hip, knee and ankle, position 3

Applying the first derivative to the equations 34, 35, 36 and through a matlab script, we obtained angular velocity graphs for the hip, knee and ankle as shown in Figure 12.

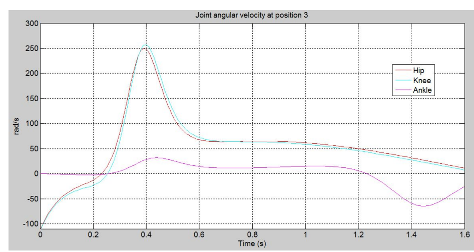

Figure 12. Angular velocity hip, knee and ankle position 3

These graphs show the second derivatives of the equations 34, 35, 36 using a script in matlab we obtain the angular acceleration for the hip, knee and ankle as shown in Figure 13.

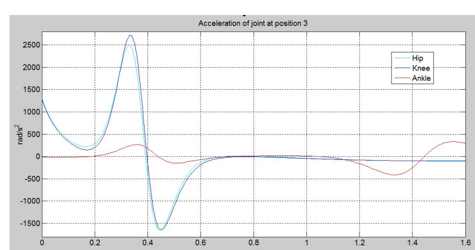

Figure 13. Angular acceleration hip, knee and ankle position 3

Using Equation 33 we get the respective torque as shown in Figure 14.

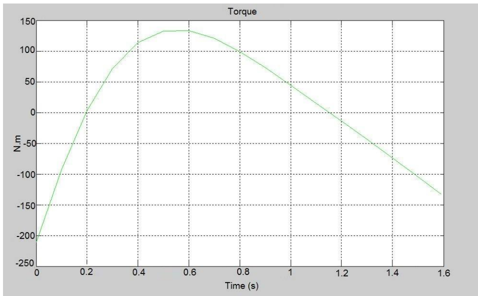

Figure 14. Torque developed by the knee articulation for the getting up

IV. ANALYSIS OF RESULTS

In Figure 8 we observed the possible initial conditions that may occur in the sitting- standing cycle that are given by the positions that people could take while resting, for this analysis it was considered the third position (Figure 6); its path is shown in Figure 7, which shows that the hip and knee angles have similar angle relative trajectories because it is measured in the sagittal plane which shows a similar functionality of hip and knee, as its angular velocity that is observed in Figure 12, the point of maximum torque is generated at the start of the lifted as it is necessary to overcome the resistance produced by a body at rest against to a body in movement. Figure 13 shows the acceleration, we observed a maximum positive value which indicates the start of lifting , and a negative peak indicating a deceleration to stop the inertia accumulated in the body.

V. CONCLUSIONS

To estimate the torque experienced by the knee when a person stands up from a chair, we used the model of an inverted pendulum, with this model we estimated that the maximum torque that the knee would experiment is a value of -200Nm (applying equation 33), which is generated at the time of lifting because the part of the femur has its maximum length in respect to the vertical axis and the resistance presented by the body at rest to take a movement. It should be emphasized that equation 33 clearly shows that the torque has a relationship with the acceleration and the speed and that the obtained torque it's located under the conditions of a normal lifting.

REFERENCES

[3] Dra. Ledia H. Gondora Garia, Dra. Cruz M. Rosales Garcias, "Articu- lacion de la Rodilla y su Mecanica ArticularMedisan, 2003"

[4] "DISEÑO E IMPLEMENTACIÓN DE UN EX-OESQUELETO MECANICO LATERAL IZQUIERDO PARA LA REHABILITACION HUMANA"; Nelson Patricio Mena Yépez, Paúl Cristóbal Veloz Caiza; Proyecto previo a la obtención del título de Ingeniero en Electrónica y Control; Escuela Politécnica Nacional.

[5] Diseño, Fabricación y Control de un péndulo doble, Juan Carlos Albarrán Castro, Universidad Nacional Autónoma de México, 2009.

[6] Biomecánica de la rodilla y lesiones, Available Online: http://www.muscleblog.es/2010/09/biomecanica-dela-rodilla-y-lesiones-sentadilla-profunda-vs-sentadilla-horizontal

[7] Control Approaches for robotic knee exoskeleton and their effects on human motion, Tradej Petrci, Andrej Gams, Tadej Debevec, Leon Zlajapah, Jan Babic, Department of Automation, Biocybernectics and Robotics, Jozef Stefan Institute, Jamova 39, Ljubljana, 100, Slovenia.

[9] Vera Luna Pedro, Biomecánica de La Marcha Humana y Patológica, Instituto de Biomecánica de Valencia,

[10] R.L.Huston, "Principes of Biomecanics," Taylor & Francis,2009

[11] Hernández Stengele Francisco, Colección de Tesis Digi- tales. Univer- sidad de las Américas de Puebla. Escuela de Ingeniería y Ciencias. Departamento de Computación, Electrónica y Mecatrónica. Diseño y construcción de prototipo neumático de prótesis de pierna humana. 14 de mayo de 2008.

[12] Software "Open Sim" Available Online: https://simtk.org/home/opensim

[13] [10] [11] [12] [13] General Electric Company, corporate research and de- velopment, Research and Development Prototype For Machine Augmentation Of Human Streng and Endurance Hardiman I Project, Mayo, 1971. [11] Zoss Adam, Kazerooni H., Design of an Electrically Actuated Lower Extremity Exoskeleton, Advanced Robotics, Vol. 20, No. 9, VSP and Robotics Society of Japan 2006. Available Online: www.vsppub.com

[14] Zoss Adam, Kazerooni H., Chu Andrew, On The Mechanical Design Of The Berkeley Lower Extremity Exoske- leton (BLEEX), Department of Mechanical Engineering, Uni- versity of California, Berkeley, CA, IEEE/RSJ International Conference on Intelligent Robots and Systems, 2005.

[15] Pratt Jerry E., Krupp Benjamin T, Morse Christopher J., Collins Steven H., The Roboknee: An Exoskeleton for Enhancing Strength and En- durance During Walking, IEEE International Conference on Robotics & Automation New Orleans, April 2004.

[16]] "Articulación de la rodilla y su mecánica articular", Available Online: http://www.bvs.sld.cu/revistas/san/vol7_2_03/san13203.htm.

[17] "DISEÑO E IMPLEMENTACIÓN DE UN EX-OESQUELETO MECANICO LATERAL IZQUIERDO PARA LA REHABILITACION HUMANA"; Nelson Patricio Mena Yépez, Paúl Cristóbal Veloz Caiza; Proyecto previo a la obtención del título de Ingeniero en Electrónica y Control; Escuela Politécnica Nacional.

[18] "Anatomía con orientación clínica", Keith L. Moore, Arthur F. Dalley, Anne R. Aur.

[19] "Anatomía y movimiento humano, estructura y funcionamiento", Nigel Palastanga, Derek Field, Roger Soames.

[20] "Articulación de la rodilla y su mecánica muscular", Dra. Ledia H. Góngora García, Dra. Cruz M. Rosales García, Dra. Isabel Gonzalez Fuentes, Dra. Nayra Pujals Victoria.

[21] "Acquisition and analysis of angles between the hip and knee during the sit-up process through the kinect sensor", Encalada, F. and Penafiel, J. and Becerra, P. and Idrovo, A. and Carreno, J. and Flores, J. and Urgiles, F., Health Care Exchanges (PAHCE), 2013 Pan American, April 2013.

[22] "Creation of the Biomedical Engineering Research Group GIIB-UPS at the Salesian Polytechnic University", Villa, A.C. and Urgiles, F., Andean Region International Conference (ANDESCON), 2012 VI, Nov 2012.

[23] "Analysis of movements during the process of the march to ascend stairs by means of sensor Kinect", Valencia-Redrovan, D.P. and Hurtado-Ortiz, J.P. and Carrion-Torres, B.O. and Montesdeoca-Contreras, J.C. and Bermeo-Maldonad, A.V. and Urgiles-Ortiz, P.F., Health Care Exchanges (PAHCE), 2013 Pan American.