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ASSESSMENT OF HUMAN BIO-BEHAVIOR DURING GAIT PROCESS USING *LIFEMOD* SOFTWARE

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Abstract. In this paper we present a set of observations concerning the analysis and assessment of human bio-behavior during gait process. In the first part of the paper the fundamental and theoretical considerations of the gait process are approached and aspects connected to malfunctions are expressed. In the second part of the paper we present the modeling methodology using the LifeMOD software, while in the third part the results and conclusions are presented.

Keywords: *gait, modelling, bio-behavior, LifeMOD, rehabilitation*

2000 *Mathematics Subject Classification*: 92F99.

1. Introduction

A traditional definition of gait is a repetitive sequence of limb movements meant to safely advance the body with minimum energy expenditure, but for a good and complete analysis, it is necessary to understand that this action requires higher cognitive neural function and a properly functioning neuromuscular system to achieve its correct execution and that obvious it is far from being a simple automated task. The act of walking has two basic requisites: first is the **periodic movement** of each foot from one position of support to the next; and the second is **sufficient ground reaction forces**, applied through the feet, to support the body. These two elements are necessary for any form of bipedal walking to occur, no matter how distorted the pattern may be by underlying pathology (Vaughan et al., 1999). This periodic leg movement is the essence of the cyclic nature of human gait (Allison S. Arnold et al., 2007).

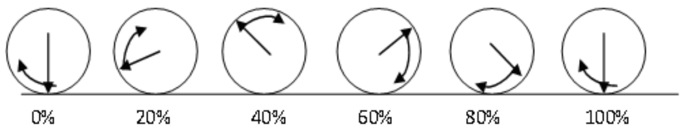

Figure 1: A rotating circle shows the cyclic nature of forward progression in gait process

There are eight events in human gait cycles and for a healthy human body they are sufficiently general to be applied to any type of gait: initial contact (0%); loading response (0-10%); mid-stance (10-30%); terminal stance (30-50%; pre-swing (50-60%); initial Swing (60-70%); mid-swing (70-85%); terminal swing (85-100%). The cyclic nature of human gait is a very useful feature for reporting different parameters. There are hundreds of parameters that can be expressed in terms of the percent cycle and but we chose for the displacement evaluation only the ground reaction force and muscle activity to illustrate the movement of human body in gait process. According to other researches there are **five key elements for normal gait like**: stability in stance (foot and ankle); clearance (of foot) in swing; pre-positioning of foot (terminal swing); adequate step length; energy-efficient fashion (normal energy expended 2.5 kcal/min, less than twice than those used for just standing or sitting). In order to assess and estimate the gait cycle from its malfunctions modeling and analysis point of view we need to admit the human body in a 3D reference system and establish the walking, balance or stability directions. In this respect we position and measure the human motion about the three axes: X (side balance direction), Y (displacement direction) and Z (bipedal stability direction) (Kent Van der Graaff, 1998).

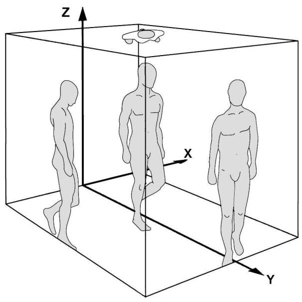

Figure 2: 3D coordinate system for the human body behavior analysis

A major aspect for the gait analysis is personalizing the body segment parameters of the individual subject, that mean: **mass** in kilograms of the individual segments (e.g., thigh, calf, foot); **centre of gravity**-location of the individual segments relative to some specified anatomical landmarks (e.g., proximal and distal joints); and **moments of inertia** of the segments about three orthogonal axes that pass through the segment centre of gravity. The anthropometrical measurements of the human body segments can describe a series of the locomotion system specific features. But these aspects will obviously provide a reasonable estimate as a first approximation, as it does not take into account the variation in the shape of the individual segments during gait process or the variations of human body in time. Each of the lower extremity segments (thigh, calf, and foot) may be considered as a separate entity. Modeling the human body as a series of interconnected rigid links is a standard biomechanical approach (Tozeren A., 2000) but it is necessary to improve this theory using the comparison between model and recordings. When studying the movement of a segment in 3-D space we need to realize that it has six degrees of freedom and simply means that it requires six independent coordinates to uniquely describe its position in 3-D space (three Cartesian coordinates X,Y,Z and three angles of rotation as Euler angles). For that it is necessary to measure the 3-D positions of at least three non-collinear markers on each segment to accomplish the information about human body in gait

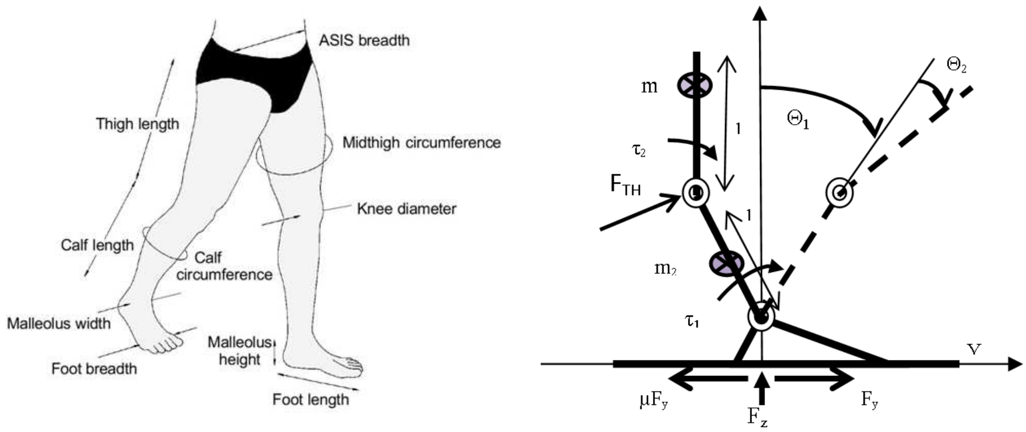

Figure 3: Anthropometric data of the lower extremity required for the prediction of body segment parameters and the model of human leg in walking process

process. The disabilities that are going to be studied are restriction imposed to the equations defining motion, position and human body bio-mechanical behavior (Baritz M., Cotoros D., Cristea L., 2008).

2. Modeling Methodology of Human Gait Using *LifeMOD* Software

The equation of motion of the model consists of two parts: the rotational dynamic of the two links and the walking dynamic of the foot.

The equation of motion of the links is expressed as follows:

$$[M]\ddot{\theta} = [N]\dot{\theta}^2 + [G] + \tau + F_{TH} \tag{1}$$

Where $[M]$ is the mass and inertia matrix; $[N]$ is the Coriolis and centrifugal force matrix; $[G]$ is the gravitational force; τ is the matrix of torques angles and F_{TH} is the thrust force.

The model of the walking human body model is presented in figure 3 and it was used to build gait simulation with *LifeMOD* software. Starting from a pre-defined skeleton module and considering the anthropometrical database

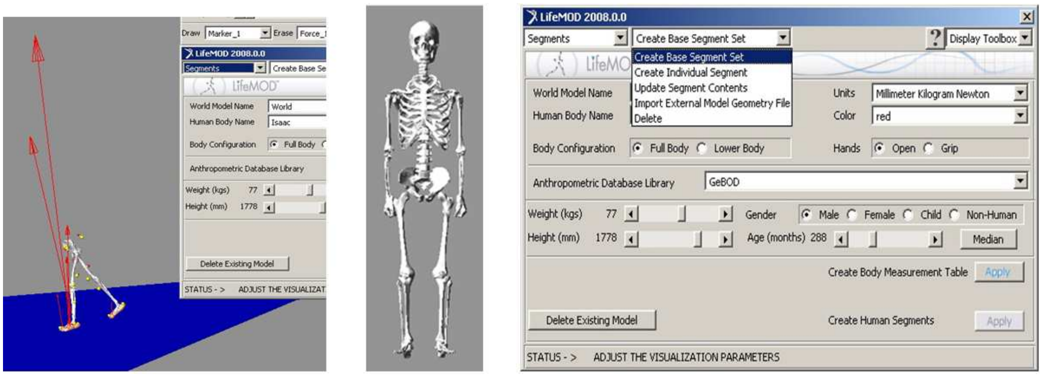

Figure 4: Creating the anthropometrical modeling database

NASA-STD-3000 we build the shape of the human inferior locomotion system with direct contact to the walking support.

For modeling human gait we considered a series of data connected to motion, trajectory, velocity or acceleration but at the same time we introduced the boundary values of the gait type (normal, malfunction of the right or left foot, jumps or steps, slips or sliding on plane surfaces etc.).

The modeling stages aim at introducing data both for the normal mode and for the one used to model a certain gait type in order to simultaneously visualize these differences.

3. Results and Conclusions

Following the analysis of different modeling alternatives created by *Life*MOD, in a normal way and with imposed disabilities we discovered a series of aspects correlated with the results obtained during the investigations upon a human subject in the same conditions. These investigations and recordings, obtained by help of a force and moments acquisition system along three directions (Kistler force plate) confirm the shape of the contact force (between feet and displacement surface) variation.

Thus, for a quick response in the analysis of the gait type and forces developed in the subject locomotion system, the created model can estimate and correlate data at different recording times and respectively for different anthropometrical dimensions or mobility restrictions. From the recordings performed using the experimental device, the most important is the evolution of the contact force between the foot and support, considering no sliding between them

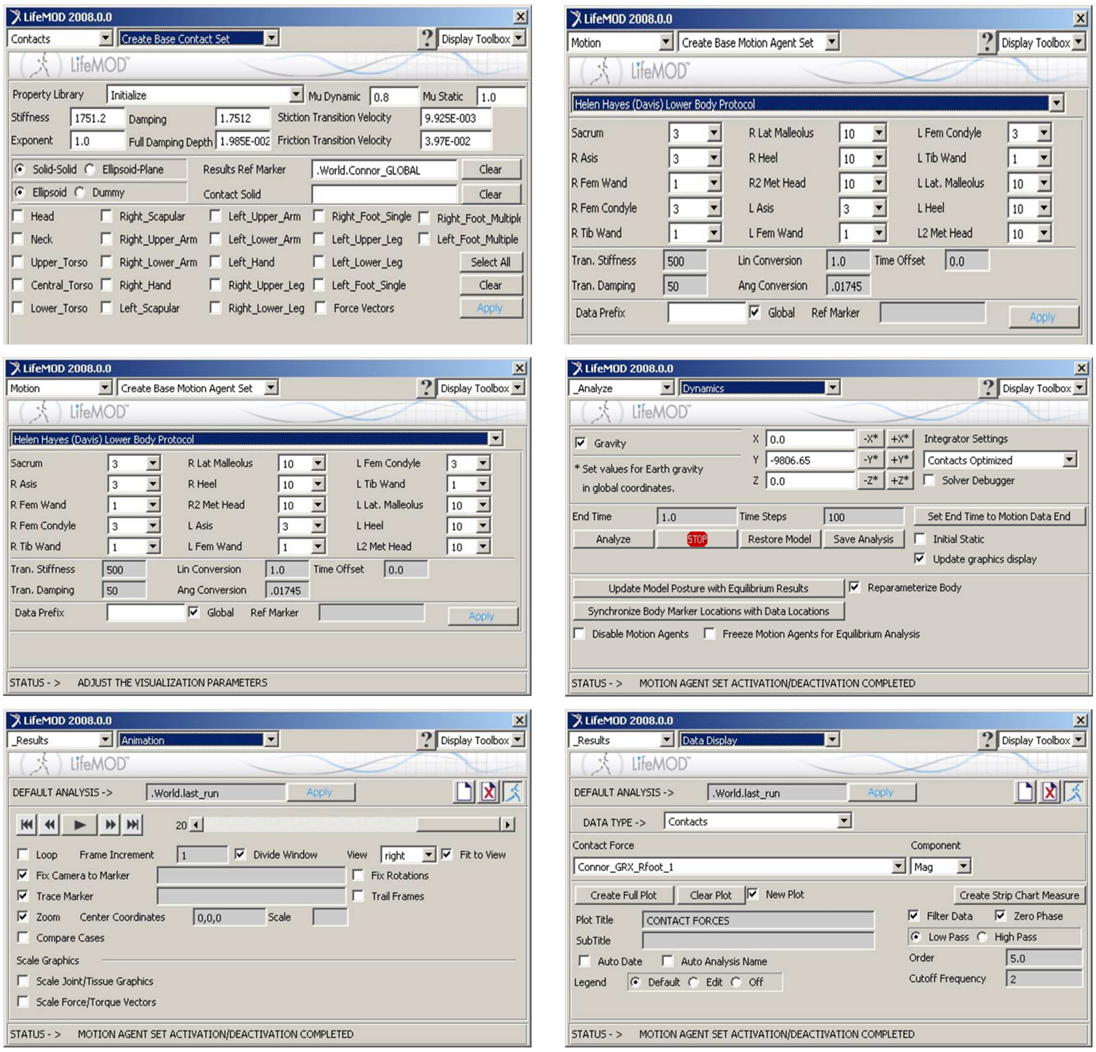

Figure 5: Stages of accomplishing the gait process modeling, simulation and visualization

and which emphasize the precise moments when this contact takes place. In these simulations, muscles generated about half (57±74%) of the knee extension acceleration during the extension phase and the other half was provided by velocity-related forces that arose from the rotational motions of the limb segments. Muscles generated nearly all of the knee flexion acceleration during the braking phase (Baritz M., Technical report, project 2007).

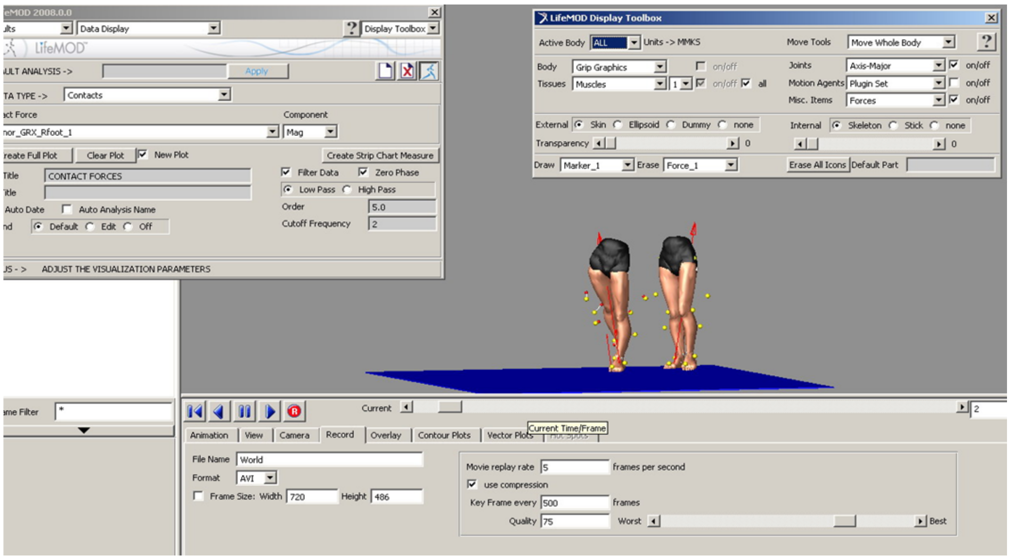

Figure 6: Comparison of the initial moment of starting the gait cycle between the two gait variants (normal and malfunction of the right leg-knee)

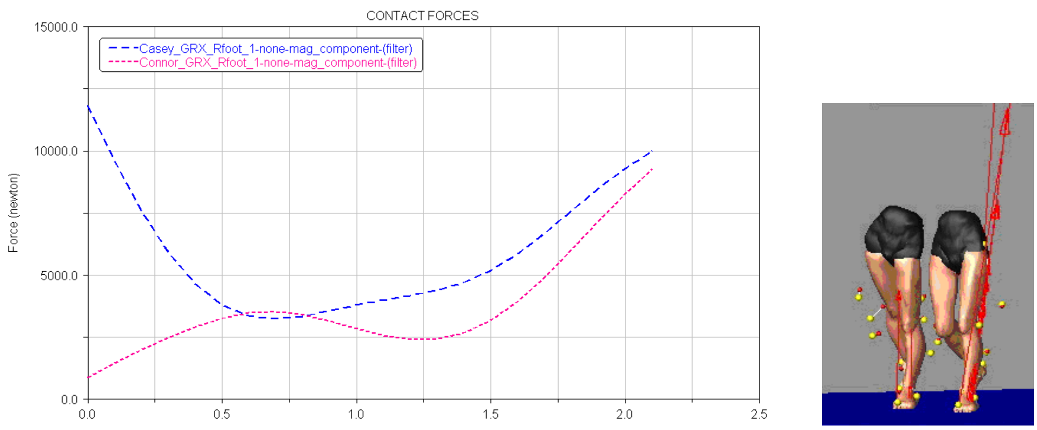

Figure 7: Graphical representation of the contact force and models created for both situations (normal and imposed disability)

Muscles on the stance limb, particularly the hip abductors, extensors, and flexors, had a major influence on motions of the swing-limb knee in the simulations. These muscles, in combination with their induced ground reaction forces, accelerated the pelvis, simultaneously inducing reaction forces at the swing-limb hip that accelerated the thigh and knee (Anderson F.et al. 2003).

Figure 8: Variation of the contact force between the foot and support (subject with locomotion disability)

The modeling and simulation structure, briefly presented for this case represents the subject of a more extended research, which allows the developing of an investigation-assessment-rehabilitation protocol for the hip implant patients (Baritz M. et al., 2008).

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