About the Simulation of the Human Knee Joint for Walking Locomotion

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Abstract: *Human knee is the most important joint used in locomotion. Scientific studies are very difficult to realize because of the complexity of this joint, even they are made in a static mode. This paper presents a study method for the human knee and the necessary steps in order to obtain a 'virtual knee joint'. For this purpose it was used a CAD parametric software which permits to define models with a high degree of difficulty. First, it was defined the bone components as femur, tibia, fibula, and patella. The obtained model was prepared for kinematics and dynamic simulation in the cases of walking locomotion. The input functions and parameters for the knee joint simulation were: the masses of the bone elements, the force applied on femur bone and the driver angle in the knee joint. The behavior of the virtual knee can give important informations which can be used in the fields of robotics, medicine sciences and medical robotics.*

Keywords: *bio-mechanics, human locomotion, dynamic simulation, robotics*

I INTRODUCTION: THE ANATHOMICAL ELEMENTS OF THE HUMAN KNEE

The knee joint is an important articulation of the human locomotion system and it is made up of bones, ligaments, tendons and cartilages. This the reason why this articulation is the most complex of the human body, studies being, thus, truly difficult to make, even when the analyzing is done in a motionless position.

The most important bones are: The femur – the longest bone of the thigh; The tibia – the longest bone of the lower leg; The fibula – the smallest bone of the lower leg. The knee joint system is shown in Figure 1.

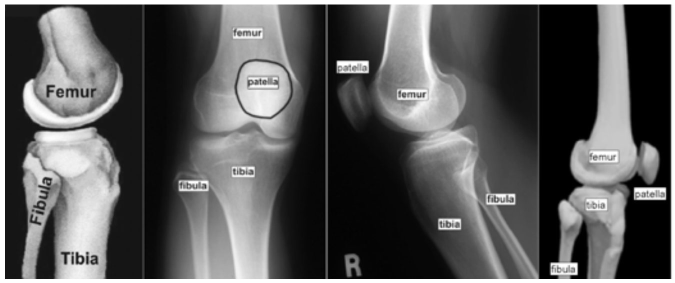


Figure 1
The knee joint system in different views

II THE VIRTUAL MODELS FOR THE BONE COMPONENTS OF THE HUMAN KNEE JOINT

1 The Study of the Real Bone Components

To elaborate the 3D virtual model for the knee joint were studied four of the main components such as: femur, tibia, fibula and patella. First, for these bones were made pictures from different angles and these were measured (Figure 2). Also, were measured the masses for each component.

To obtain the pictures was used a Spycam 100 digital camera having the storing capacity of 20 photos. Also, the bones were supposed over sheets of paper with lines drawn from 10 to 10 millimeters.

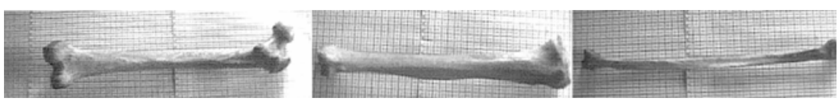
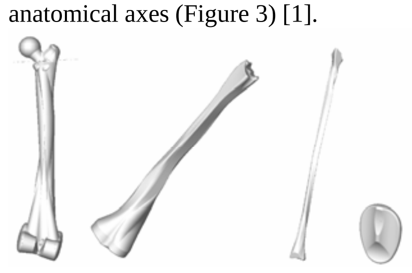


Figure 2
The pictures of the main bone components of the human knee

2 The Virtual Models of the Bone Components

To obtain the 3D model was used SolidWorks – a CAD software of third generation. Using the measurement made on real bone component and after the identification of the simple shapes was starting the modeling operation. The modeling operation was based on measurements made on different section of the bones. Unifying these sections in solids were obtained the models of the femur, tibia, fibula and patella. These components were assembled and that operation was based on the measurements and using the knowledge about the geometrical and anatomical axes (Figure 3) [1].



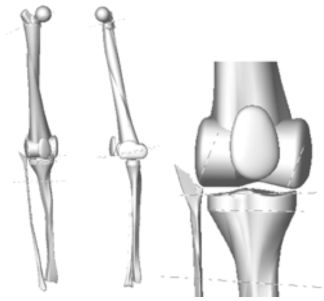


Figure 3
The virtual models of the bone components of the human virtual knee [1]

III THE SIMULATION OF THE VIRTUAL HUMAN KNEE

1 The Input Parameters for the Simulation of the Virtual Knee Joint

To complete the virtual mechanical model it was necessary to define the next input parameters:

1) the dimensional and geometrical elements of the components of the mechanical assembly. These elements were defined when the bone components of the human knee joint were generating in the CAD environment.

2) the masses of the components and the entire inertial behavior for the mechanical defined model. The masses of the components were attached to the model after the step of the geometrical modeling using the average densities so, the virtual bone models to be almost identical to the real studied models [5].

The virtual environment permits the automatically calculus of each main geometrical and inertial parameter for each bone component (the position of the mass center reported to the general coordinate system, principal moments of inertia a.s.o.).

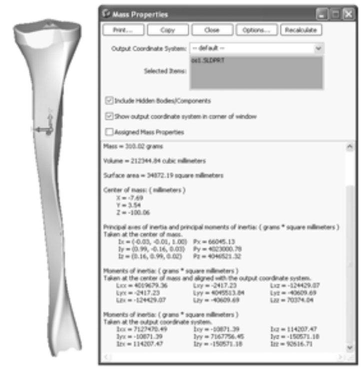


Figure 4
The geometrical and inertial parameters for the tibia bone [5]

In Figure 4 was presented the inertial values for the virtual model of tibia bone [5].

3) the forces applied to the femur (Figure 5) appear because of the action of the gravitational forces, which had a different variation for the main types of locomotion (walking, running, jumping) [5].

Figure 5
The main force in femur bone [5]

For walking was used an average velocity v_{med}=5 km/h. At the start of the walking (starting from vertical statically position the weight force was disposed equally over the two symmetrical parts of the human body. From that observation we can conclude that the start value of the force, which had the action over the femur, was different from nil, that reaching the nil value at the initiation of the next step. For that force was proposed the temporal variation from Figure 6 using a complete cycle of locomotion with duration of 1.152 seconds [5].

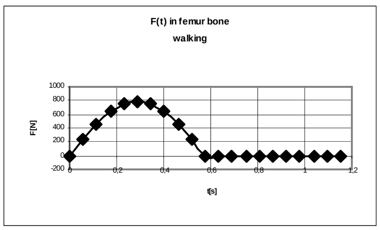


Figure 6
The absolute value of the femur bone force for walking locomotion [5]

4) The angle variation in knee joint was made by the action of the muscles and depends by the type of locomotion (walking, running, jumping). That angle and its temporal variation for walking locomotion were presented in Figure 7 [5].

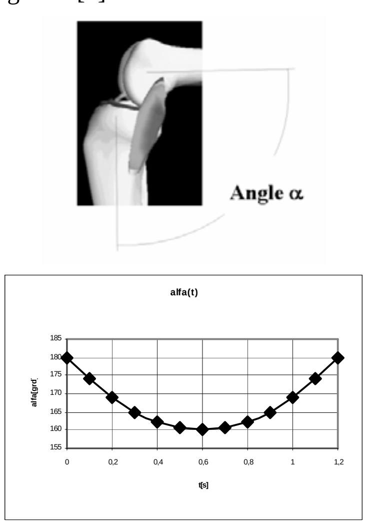


Figure 7
The angle α in human knee joint [5]

5) The function for reaction force from tibia bone made by the contact between the foot and the ground will be found if the simulation will work properly (using the successive iterations method) [2], [3].

2 The Results of the Simulation of the Virtual Human Knee

a) The Walking Locomotion (simulation movie and diagrams)

In Figure 8 were presented the main frames of the simulation movie.

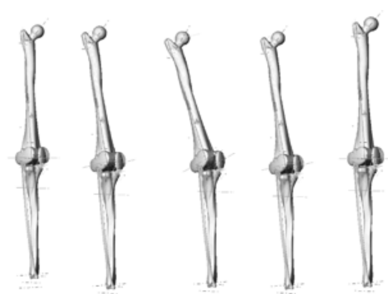
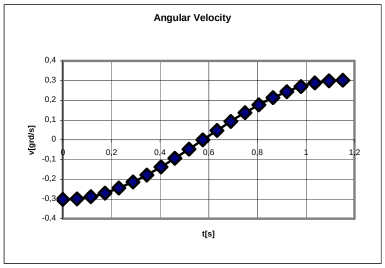


Figure 8
Five distinctive frames of the simulation movie

Also in Figure 9 were presented the angular velocity and the angular acceleration in the joint of the knee.



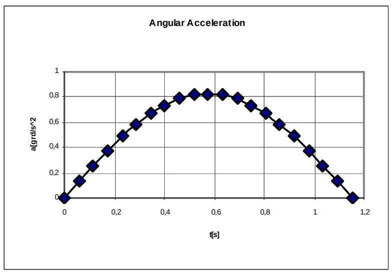


Figure 9
The angular velocity and acceleration in the knee joint

b) The Walking Locomotion (mathematical models)

Based on the diagrams and the tables of results were defined the next functions for the main parameters:

- the angle in the knee joint:

$$\alpha = 180 - 19.999 \cdot \sin(2.726 \cdot t) \quad (1)$$

- the angular velocity in the knee joint:

$$v_\alpha = -54.519 \cdot \cos(2.726 \cdot t) \quad (2)$$

- the angular acceleration in the knee joint:

$$a_\alpha = 148.62 \cdot \sin(2.726 \cdot t) \quad (3)$$

- the magnitude of the force in femur bone:

$$F_1 = \begin{cases} 784.8 \cdot \sin(5.4531 \cdot t)\_\,pentru\_\,t \in [0,0.6] \\ 100 \cdot \sin(5.4531 \cdot t)\_\,pentru\_\,t \in (0.6,1.2] \end{cases} \quad (4)$$

- the magnitude of the force in tibia bone:

$$F_2 = \begin{cases} -517.968 \cdot \sin(5.4531 \cdot t)\_\,pentru\_\,t \in [0,0.6] \\ -66 \cdot \sin(5.4531 \cdot t)\_\,pentru\_\,t \in (0.6,1.2] \end{cases} \quad (5)$$

- the magnitude of the force in fibula bone:

$$F_3 = \begin{cases} -258.984 \cdot \sin(5.4531 \cdot t)\_\,pentru\_\,t \in [0,0.6] \\ -33 \cdot \sin(5.4531 \cdot t)\_\,pentru\_\,t \in (0.6,1.2] \end{cases} \quad (6)$$

Conclusions

The paper is a part of the themes of high actuality which use the knowledge from various domains (anatomy, surgery techniques, orthopedic, mechanics, mechanisms, bio-mechanisms, computers science).

The knee is the most complex joint from the human body, but this paper proves the mechanical studies can be made starting from anatomical knowledges. The behavior of the virtual knee can give the important informations which can be used in the fields of robotics, medicine sciences and medical robotics. Also, on the virtual knee joint can be attached virtual prosthetic elements for virtual post-surgery simulations.

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