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BIOMECATRONIC SIMULATOR DEVICE OF THE INFERIOR LIMB

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Abstract: The scientific work presents certain preoccupations of the authors regarding improvements brought to the equipment's of rehabilitation by type of prosthesis or orthesis of the superior or inferior limb.

This work presents the achievement of a biomecatronic simulator device for the inferior limb with a pneumatically operation.

With this simulator it can be studied the variation of the forces and the reaction moments in the inferior limb articulations under other factors. With the base structure of the simulator device there can be created structures of the prosthesis devices of the inferior limbs.

1. INTRODUCTION

Making a similarity between the general structure of a robot and the structure of the human being, an important subsystem is the mechanical system of the robot, which can be similar with the bony system of the human being (human skeleton), defining the nature and the amplitude of the movements which can be realized.

So the mechanical system of the robot has the function to realize the laying of the manipulated objects, and the function of transmitting the mechanical energy necessary to interact with the environment. Regarding the mobile robots, the mechanical system has the role of realizing the locomotion and also to transmit the mechanical energy necessary for the interaction with the ground for making possible the walk. For the human being this role is realized by the inferior limbs.

We can tell that in the day by day life the locomotion capacity is influenced by the quality of the bone system of the inferior limbs, and also by the quality of the articulations between the component elements. The capacity of transmitting of the mechanical energy necessary for the movement is influenced by the quality of the actuation system, which is similar with the muscle system of the human being.

In the day by day life there are a lot of factors which cause malfunctions of the locomotion system. The main causes and the more numerous are traffic accidents, work injuries of different causes (fallings, electrocutions, impacts etc.).

In some situations these causes bring to the necessity of partial or total amputation of the inferior limbs. In these situations for the reconstruction of the locomotion capacity there can be used robotic equipments called prosthesis. These equipments provided with auctioning and sensorial systems can be considered mecatronical systems and can replace the non-existent limb.

Other causes for the diminishing of the locomotion capacity are specific diseases of the joints, of the bone and muscular system. In these cases it is necessary to partially replace some elements, respectively the joints or the use of some robotic equipment, which can supplement the function of the existent elements, called orsthesis.

For the conception and the realization of these mecatronical products there must be studied all the factors which bring to the correct realization of the locomotion. For this the inferior limb can be considered an overlap of systems, devices, functions after well determined laws. The research of the joint system under mechanical appearance can be done by using the classical and modern engineering techniques of experimental calculation. The bone and joint system of the inferior limb can be considered a spatial distortion of the structure with a appreciable complexity regarding the geometry, the elastic property and the assignment. To study this system we can use the molding and simulating method of the system.

A synthesis of the mold can be made taking into account the following aspects:

- Static, cinematic or dynamic mold;
- Realization of a scale or twist mold;
- Used materials;
- Connections to which is subject and the loading of the mold, which must be realized in conditions closely to the real ones for the studied situation.

The mold is obtained by simplifying the original phenomena. The mold must be conceived and investigated so it can be determined in certain precision limits the behavior of the original system, by determinations made on the mold.

A precisely molding of the joint's solicitations is very hard to realize because the joints are vary complex structures with a complicated spatial geometry and can vary depending the age, sex, waist, profession, environment conditions etc. And also vary from person to person.

For laboratory studies of the inferior limb behavior at different loads (jobs), it has been conceived a simulating device with pneumatic auctioning.

2. SKELETON STRUCTURE AND THE MUSCLES OF THE INFERIOR LIMB

The inferior limb skeleton is composed from the pelvic girdle and free inferior limb skeleton and presents a series of particularities impregnated by the ortostatism and two legs locomotion.

The inferior limbs skeleton assures stability, sustain the weight of the body and absorb the force actions while running or jumping. The three parts of the inferior limb are: waist, which extends from the pelvis to the knee, calf, which extends from the knee till the ankle and the sole. (Figures 1 and 2)

The inferior limb skeleton presents in essence three basic joints:

- pelvian-femur joint, composed from the femur's head (spherical) and the pelvian pocket (acetabulum), which is a spherical joint;
- calf-femur joint, trohlean joint (Knee)
- ankle joint where the tibia joints with the talus (bone of the ankle).

The main elements of the skeleton (the conection elements) are: femur (waist's bone) and tibia (the biggest bone of the calf).

The legs (sole) sustain the body weight and mantain the ballance. The legs action like levers which push the body forwards while moving. Each leg has 26 bones, which joined with the ligaments facilitates the function of the leg – to support the weight and the movement. Between these bones there are a series of joints. Based on the structure of these skeletons are conceived and realized any prosthesis or orsthesis.

Structure of the inferior limb is presented in figure 3.

Fig. 1 Structure of the inferior limb- calf and sole

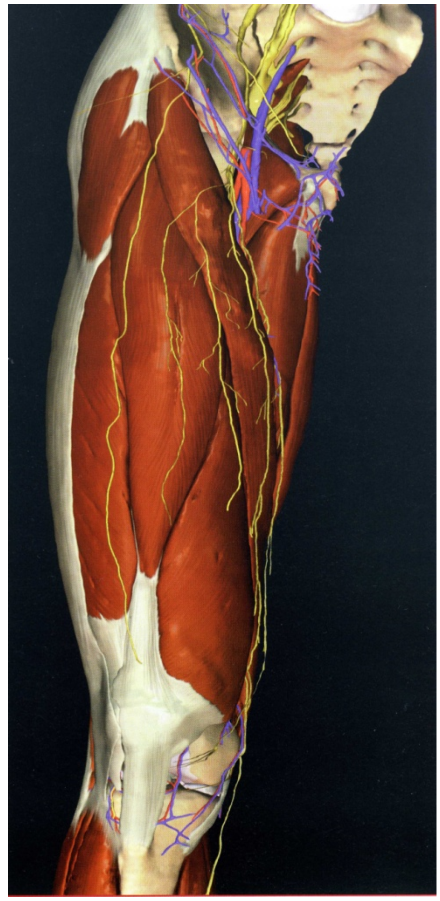

Fig.2 Structure of the inferior limb- waist and knee

3. THE CHINEMATIC MOLD OF THE INFERIOR LIMB.

The chinematic chain contains modules, which can be considered rigid in the cinematic molding, composed from: thigh, calf, foot bind together with cinematic couples according to the joints previously presented:

- The coxofemural joint is a typical spherical joint (cinematic couple of III-rd class), with tree degrees of freedom.
- The knee joint is the greatest joint of the human body, with tree degrees of freedom
  (cinematic couple of III-rd class). Here we can find a combination between rolling and sliding.
- The ankle joint it is considered also a cinematic couple of III-rd class, haveing tree degrese of freedom.

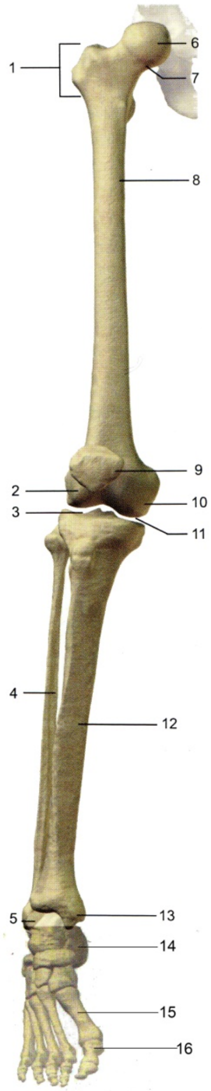

Fig. 3 Lover limb skeleton: 1.great trohanter; 2. lateral epicondil; 3. lateral condil 4. Fibula; 5. lateral maleola ; 6. femural head;7. femural nek; 8. femur;9. knee-cap;10.middle epicondil;11.middle condil; 12.tibia;13.middle maleola;14. talus;15.metatars;16.falange;

The complete cinematic mold tacking account of the shown one it is presented in figure 4, and the simplified cinematic mold is presented in figure 5.

For the complete cinematic study of the inferior limb we can consider a structure in an open cinematic chain, serial with 10 degrese of freedom, tree of a kind on each joint level presented previously and a rotation (5-ft class) of flexion – extension whit the axis in the talus body. By this movement the dorsal side of the leg is backing-off from the calf, with amplitude of 60^0-80^0.

The dimensions of the skeleton are marked with:

F – The femur lenght
T – The tibia lenght
P – The plant lenght (tars - metatars)
D – The falang lenght
B – The pelvis width (sacred bone)

For the studies of the simulator the simplified cinematic mold is token in consideration (fig. 5). The inferior limb is considered to be a structure in the open cinematic chain with 4 degrease of freedom, having 4 rotation cinematic couples [1]. The reference system $X_0O_0Y_0Z_0$ is considered to be invariable with the origin at half-length of the pelvis. A reference system is attached on each joint (cinematic couple) according to the Hortenberg – Denevitt (H – D) convention.

For the inferior limb the joint variables are presented in table 1.

The transition matrix which represents the location of the fingers against the invariable reference sistem, by writing the pass matrix from a sistem to another:

$$^0T_4 = {}^0A_1 \bullet {}^1A_2 \bullet {}^2A_3 \bullet {}^3A_4 \qquad (1)$$

$$= Rot(z,\theta_1) \bullet Trans(z,-\frac{B}{2}) \qquad (2)$$

$$^1A_2 = Rot(z,\theta_2) \bullet Trans(z,-T) \qquad (3)$$

$$^2A_3 = Rot(z,\theta_3) \bullet Trans(z,-P) \qquad (4)$$

$$^3A_4 = Rot(z,\theta_4) \bullet Trans(z,D) \qquad (5)$$

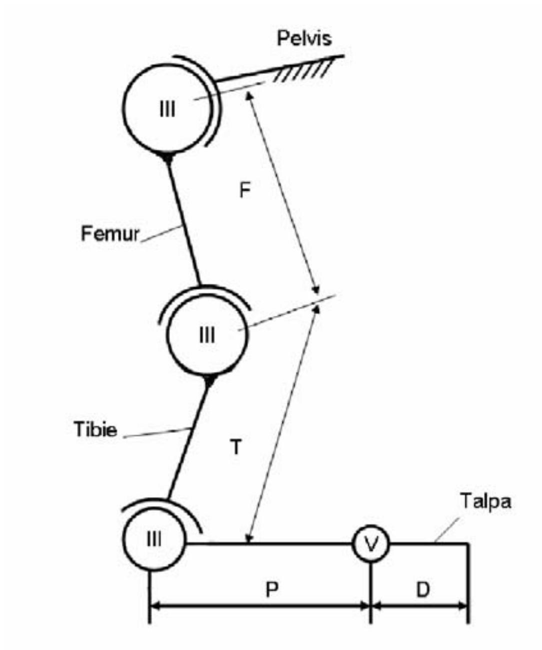

Fig. 4 The complete cinematic model

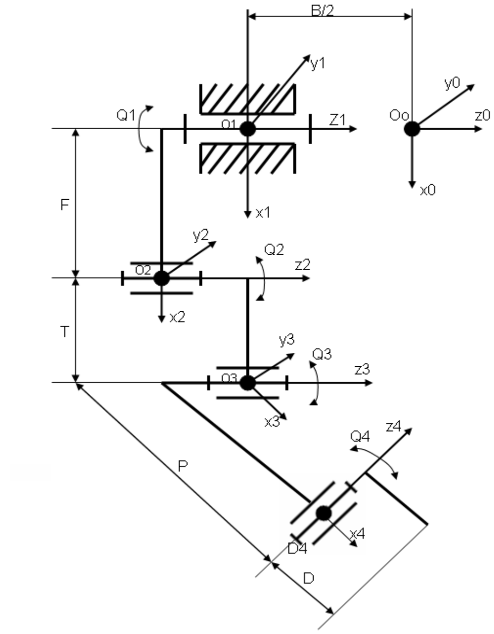

Fig. 5 The simplified cinematic model

Table 1

Joint	θ_i	B_i	L_i	α_i
1	θ_1	$-\frac{B}{2}$	F	0
2	θ_2	0	T	0
3	θ_3-90^0	0	P	0
4	θ_4	0	D	0

By writing the particular matrix, calculating the products and applying the known simplifications (cos $\theta = C_\theta$; sin $\theta = S_\theta$) is obtained:

$$ {}^0A_1 = \begin{bmatrix} C_{\theta 1} & -S_{\theta 1} & 0 & FC_{\theta 1} \\ S_{\theta 1} & C_{\theta 1} & 0 & FS_{\theta 1} \\ 0 & 0 & 1 & -\frac{B}{2} \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (6) $$

$$ {}^1A_2 = \begin{bmatrix} C_{\theta 2} & -S_{\theta 2} & 0 & TC_{\theta 2} \\ S_{\theta 2} & C_{\theta 2} & 0 & TS_{\theta 2} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (7) $$

$$ {}^{2}A_{3} = \begin{bmatrix} S_{\theta 3} & C_{\theta 3} & 0 & PS_{\theta 3} \\ -C_{\theta 3} & S_{\theta 3} & 0 & -PC_{\theta 3} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8} $$

$$ {}^{3}A_{4} = \begin{bmatrix} C_{\theta 4} & -S_{\theta 4} & 0 & DC_{\theta 4} \\ S_{\theta 4} & C_{\theta 4} & 0 & DS_{\theta 4} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{9} $$

$$ {}^{0}T_{4} = \begin{bmatrix} S_{\theta 1-2-3-4} & C_{\theta 1-2-3-4} & 0 & DS_{\theta 1-2-3-4} + PS_{\theta 1-2-3} + TC_{\theta 1-2} + FC_{\theta 1} \\ -C_{\theta 1-2-3-4} & S_{\theta 1-2-3-4} & 0 & -DC_{\theta 1-2-3-4} + PC_{\theta 1-2-3} + TS_{\theta 1-2} + FS_{\theta 1} \\ 0 & 0 & 1 & -\frac{B}{2} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10} $$

Considering the matrix of the fingers location:

$$ {}^{0}T_{4} = \begin{bmatrix} n_X & o_X & a_X & P_X \\ n_Y & o_Y & a_Y & P_Y \\ n_Z & o_Z & a_Z & P_Z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11} $$

Utilizing Matlab 7.0 programs the following cinematic equations of the reduced mold result:

$$ \begin{aligned} n_x &= S_{1-2-3-4} \\ n_y &= -C_{1-2-3-4} \\ n_z &= 0 \\ o_x &= C_{1-2-3-4} \\ o_y &= S_{1-2-3-4} \\ o_z &= 0 \\ a_x &= 0 \\ a_y &= 0 \\ a_z &= 1 \\ P_x &= D^{*}S_{1-2-3-4} + P^{*}S_{1-2-3} + T^{*}C_{1-2} + F^{*}C_1 \\ P_y &= -D^{*}C_{1-2-3-4} - P^{*}C_{1-2-3} + T^{*}S_{1-2} + F^{*}S_1 \\ P_z &= -\frac{B}{2} \end{aligned} \tag{12} $$

We can observe that the cinematic equation are relatively simple, their form is caused from the fact that all the cinematic couples have parallel axis.

4. THE DESCRIPTION OF THE SIMULATOR DEVICE

The simulator device is conceived in the first stage for simulating the movements of a single inferior limb, and may be extended for the successive simulation of movement for both inferior limbs.

The mechanical structure was conceived on the base of the simplified cinematic chain (figure 5), and operating the cinematic rotation couples is realized using pneumatic linear engine with pistons. The tenet scheme is presented in figure 6. The construction includes plaque 3, as a femur, connected at the support plaque 2 (hip) with the cinematic rotation couple 4, and in the inferior part is connected with joint 5. Support 15 at the plaque 14 acts like a tibia. Plaque 14 is connected by joint 20 to plaque 19, which acts like an ankle. The leg contains the base plaque 21, which acts like a sole, a superior plaque 22between which it can be found six force sensors. The sole is joint to the ankle by the 24-th plaque and maintained in balance by the lamellar spring 25, which acts like a attenuation element.

The whole mechanical system presented is connected to the 26-th segment, by the spherical joint 1 (pivot), which acts like the femoral body and the pelvis.

The operating system for the inferior limb contains three linear engines with pistons, with the diameter of 20mm and the length of the race of 80-100mm, FESTO type. Each engine is connected by joints to an element situated before and one after the cinematic couple on which it operates. The 6-th engine put's in movement the femur against the hip, the 10-th engine puts in movement the tibia against the femur (the knee joint), and the 16-th engine puts in movement the leg against the tibia, simulating the ankle join.

The pneumatic engines with double operations are supplied by plastic pipelines from a microprocessor with batteries, by dint of some distributors, connected at their turn by a command system.

5. Conclusions

With help of the installed sensors in the sole it can be studied the influence of the applied forces throughout the pressure of the variation over the systems joints in static or dynamic position.

On base of these studies contributions can be brought regarding the constructive optimization of prosthesis and orsthesis.

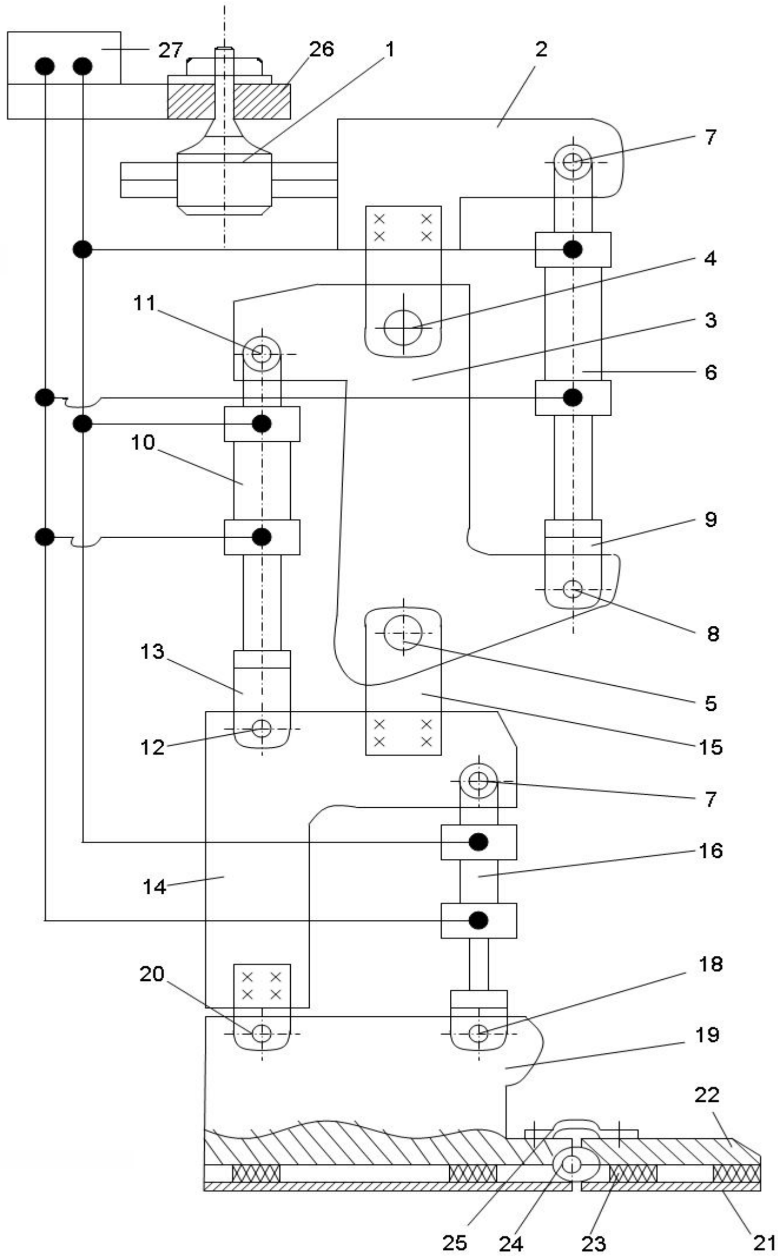

Fig. 6 - Biomecatronic Device simulator

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