

# STUDY OF HUMAN WALKING BY SIMMECHANICS

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## Abstract

**In this paper we describe our designed methods for study and simulation of human walking by SimMechanic. Simulation of human walking is useable for new design of prosthetics and therapy e.g. rehabilitation, optimization of sportsman's moves etc. Our work is focused on study of human walking by prediction and quantification. Our designed model of human body and analytical methods could be useable and widely applied in research because we designed the tools based on MatLab for study and measurement of motion.**

## 1. Introduction

In physiotherapy research and practice, there is no appropriate generally known application of expert system for identifying defects in the movement of human body. Above all, evaluation of the quality of walking is difficult and often based only on the subjective views of a medical doctor and they do not use the appropriate or accurate methods. As is known, the program MATLAB has implemented a number of toolboxes for experimenting with a lot of analytical methods. For this reason, the MATLAB program is suitable for research of characteristic of human motion. If we analyze the human walking, we can assume that the human body is mechanical system, which can be simulated in the program MATLAB Simulink and toolbox SimMechanics. Promising and little-studied method of analysis by mentioned software is the study of movement angles and forces. We decided to use for study of gait characteristics a methods that are based on the measurement of geometric properties. Quite interesting part of study, assuming that the body is composed of physical parts, is the study of angles and forces in parts of the body such as joints. This field of study of angles and load of joints is mentioned in a wide range of work. Unfortunately, there is not used to analyze the angles and load of body parts the software SimMechanics which can easy cooperate with another MATLAB toolboxes and software applications.

Applications of cyclograms and algorithms to study load of joints in SimMechanics with another MATLAB toolboxes offers wide area of applications in medicine research such as the study of possibility of new rehabilitation equipment and control systems of mechanical aids or in rehabilitation for identification of disorders.

## 2. Methods

For the modeling of the body we use Simulink respectively SimMechanic, the movement of model of the body is controlled by the data measured by motion capture system which identifies a position of points in the Cartesian coordinate system. For measure of movement we can use several methods, for example infrared (IR) camera with active markers of just cheap web camera.

We used for our application the medical IR camera with active markers (system Lukotronic AS 200). We place LED diodes markers on the measured person to the following points: malleolus lateralis, epicondylus lateralis, trochanter major and spina iliaca anterior superior. By this method we can record the movement in a three dimensional space.

Commonly human gait data consist of the recorded positions of markers on the skin/dress at the extremities of the limb segments (the thigh, the shank etc.) of a subject. In system Lukotronic AS200 is maximum number of markers 32. Measured points defined by markers placed on body are shown in Fig.1. Figure shows a sketch of the body (Fig. 1) and leg (Fig. 6) of a subject and indicates the joint angle.

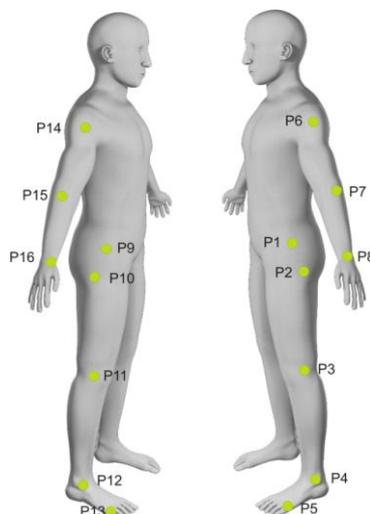


Figure 1: Draft position of the markers on the body for physiotherapeutic examination by 3D Lukotronic AS 200.

Model of human body was created in the environment of program MatLab-SimMechanics for simulation and modeling of mechanics elements of human body and their characteristic of motion. The condition for practically useable model was built a base of the model which was representing by grand block. By the help of joint actuator block we could import data which was acquired by one of designed measuring system to the body model and by other joint sensor block we could export data from the body model. System is composed of blocks of the Body and Custom Joint and the components of model form the required skeleton model. The model is designed according to human model created by Bohn and Shane who have dealt with anthropometric factors and characteristic. Thus the basic torso model is created from the head, chest torso, waist torso and the pelvic section. All blocks are movably connected by joints. Joint connections are controlled by the Joint Actuator block. This model of basic torso is ready for the animate the body, i.e. simulate the movement in the spine.

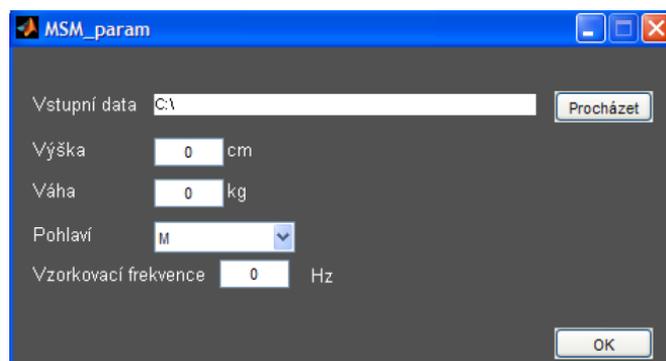


Figure 2: Dialog box for data entry the basic input parameters - height, weight, gender of measured persons/patients.

We designed the model that the user can update the mass of body. User fills in small dialog box also another characteristic of body including high, weight, and gender. By designed instruments of subprogram we compute length and weigh of each segment of subject body. For determination of individual segment weigh, center of gravity and moment of inertia exists several methods. Unfortunately any of them are not absolutely exact, so we count them only with error. We made decision to determine the segments characteristics by means of experimentally acquired coefficients. The coefficients has stochastic character and their application for average population is problematic, because the authors (Zatsiorsky, Bohn, Shan, etc.) made their experiments on different population. We used for determination of segment characteristic the Zatsiorsky's method. From mentioned characteristic we will be able to determine the loading of joint of body segments as well.

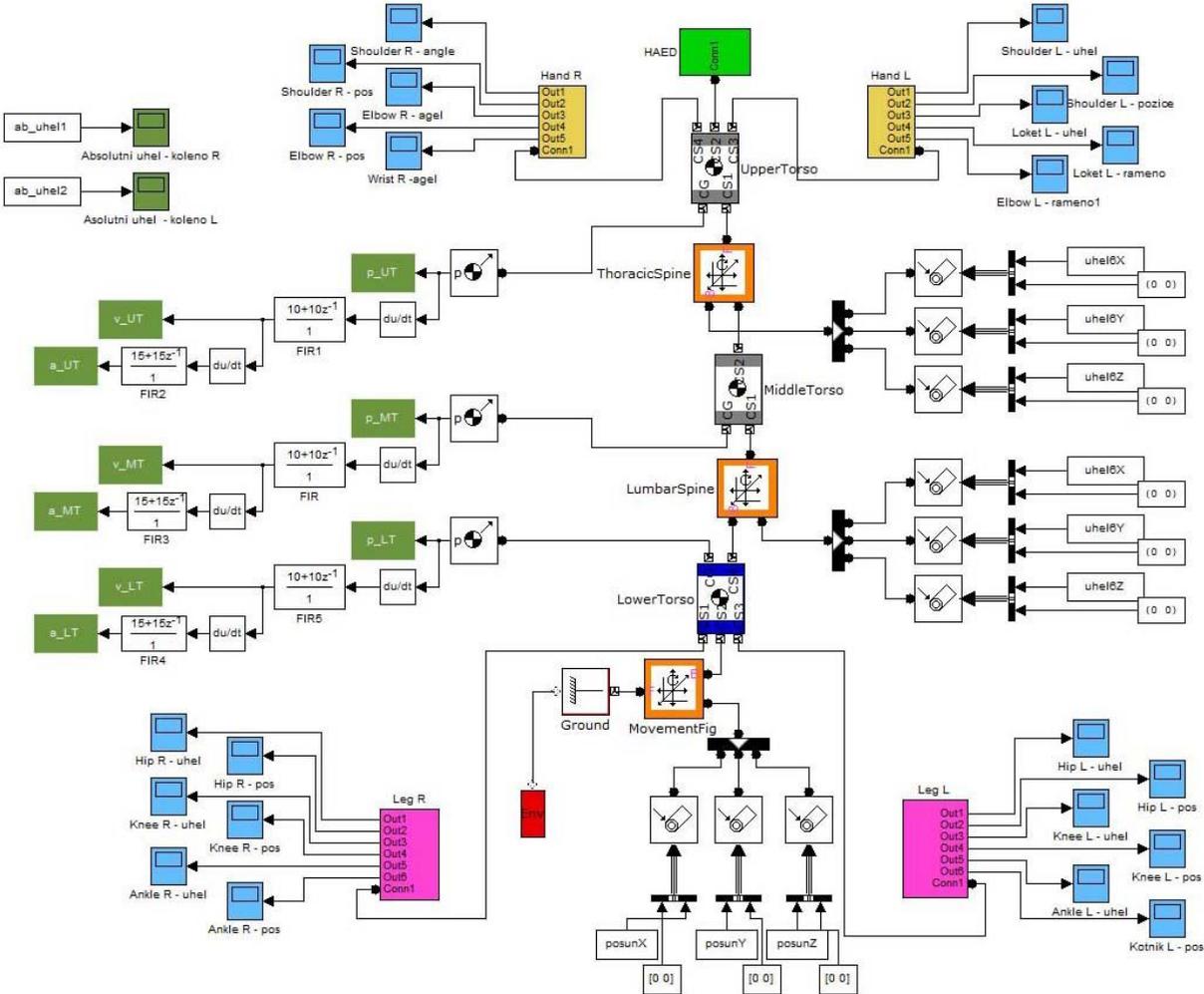


Figure 3: Model of human body created by Simulink workspace.

Upper and lower limbs of the body are due to better understanding and clarity in the subsystem. Double click on the subsystem opens the schema of subsystem, in our case the limbs. Subsystems of the left and right parts of the body are identical. Difference is only in data that are loaded into the model from motion capture systems. Subsystem of the upper limbs is connected to the thoracic part of the trunk of the body called UpperTorso by joint called Shoulder representing the human shoulder. The upper limb is created by arm (Humerus) which is connected to the forearm (Ossa antebrachii) through the elbow (Elbow).

The end of subsystem is created by joint connecting arms wrist (Wrist) with the forearm. Because the movement of body parts is in three-dimensional space, each joint is now controlled by three actuators, for each plane one. Sensors in the joints and segments provide data that are further processed. Data from the model are directly plotted by Scope blocks, or are analyzed by subroutines in MatLab, using the data for further calculations.

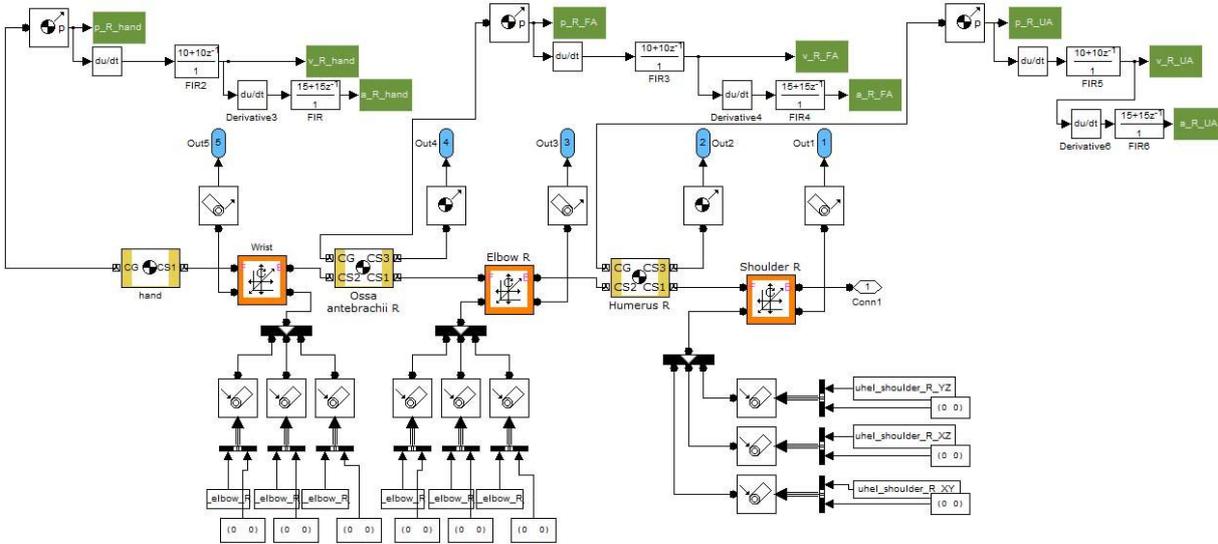


Figure 4: Model of right human arm created in Simulink workspace.

Similarly, as a subsystem of the upper limb is also designed subsystem of leg. The pelvic part of the body is through the hip joint (Hip) connected to subsystems of the lower limbs. The next two joints of lower limb are: knee (Knee) and ankle (Ankle) which are connecting blocks: femoral segment (Femur), tibia segment (Ossa cruris) and foot segment (Planta pedis).

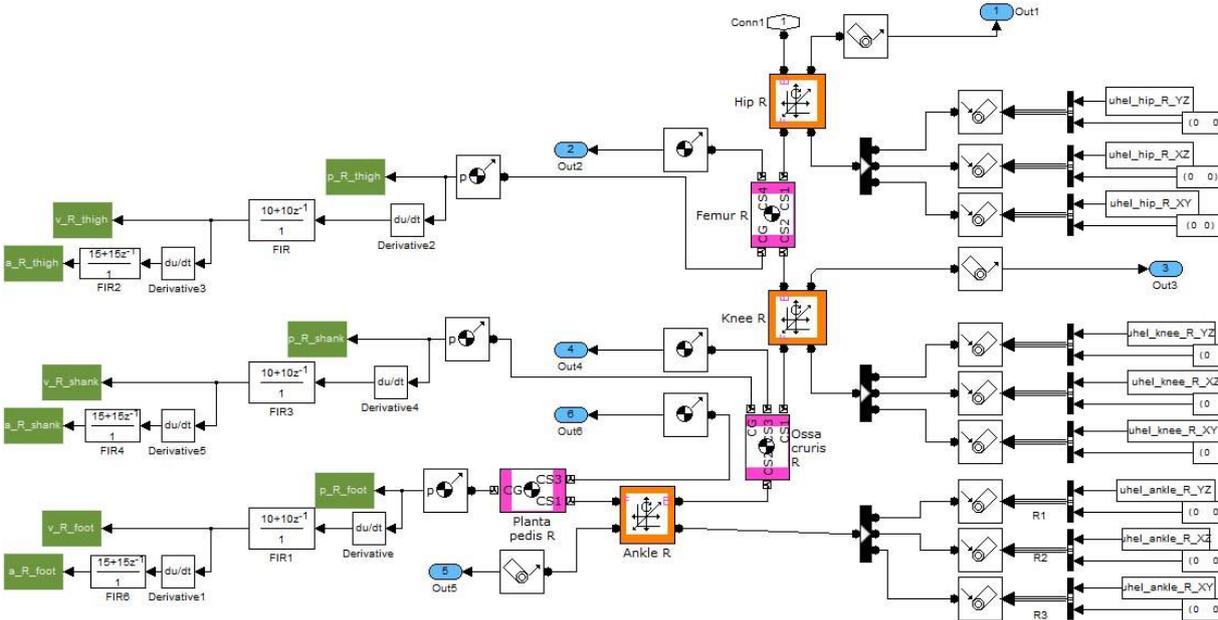


Figure 5: Model of right human leg created in Simulink workspace.

Human movement is a complex activity that we could describe the movement by many ways and many variables, depending on which of the movements characteristics we are interested in. Mathematical and physical description is very important for understanding the principle of movement and for its studies and then to evaluate its defects and abnormalities.

Angles for analysis of movement, especially walking, are very important parameters. But their evaluation by the naked eye or only video recording is very subjective and can not be quantified with such precision that would satisfy the needs. If we have information on the movement of points/markers in space and the points characterize the parts of human body, then we can use these points to define the vectors of motions of body parts. The calculation procedure is simple, it is enough to know the coordinates of two points in space. Difference of coordinates defines a vector.

The angles between each two segments are calculated by assuming the segments to be idealized rigid bodies. Based on the Fig. 6 our model (Fig 3) is able to count angles in hip, knee, ankle, shoulder and elbow. Our body model was primarily created in order to count angles in joints and takes it into the simulation of the human walking. For computing of angles we use:

$$\beta = \arccos \frac{u \cdot v}{|u| \cdot |v|}, 0 \leq \varphi \leq \pi, [\text{rad}], \quad (1)$$

for the two-dimensional system, because we assume that such knee or elbow joint have only one rotational degree of freedom. Equivalently, the calculation is performed for three-dimensional space. Where  $u$ ,  $v$  are vectors of body segments (thigh, shin, foot, etc.) represented by minimally two points, i.e. markers placed on each segment. If we are interesting in angles between segments and physical horizontal we determine the angle between vector (1,0) and vector that represents coordinates of points on the body segments evaluated in the Cartesian coordinate system.

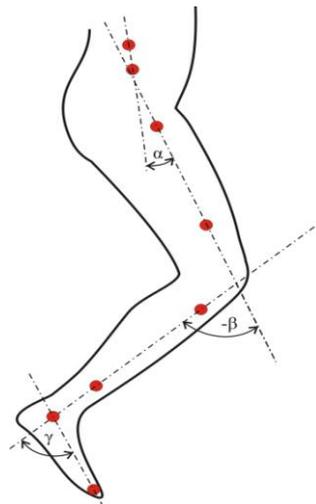


Figure 6: Angles measured during the examination of the patient's leg.

Markers are moving in space together with body segments and the individual segments of the body are moving by the translational or angular movement per unit time. Therefore, for the determination of translational and rotational speed of the individual segments/markers we are using numerical derivation. Nevertheless, the main characteristic of walking which we are concerning in biomechanics, are the forces in body parts during the periodical motion. The

forces we can calculate by the knowledge of translational and angular acceleration of segments. Translational and rotational acceleration we determine by the numerical derivation.

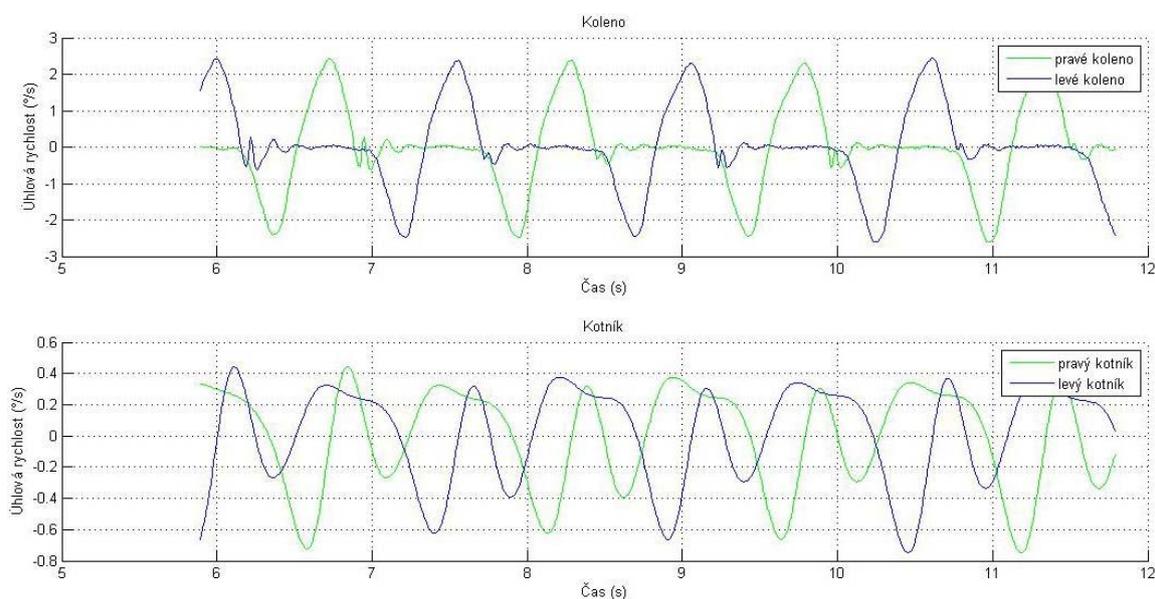


Figure 7: Graphical output from the program - the angular velocity of movement in the knee and ankle.

We can use for study of gait angles the methods that are based on the measurement of geometric properties of bilateral cyclograms (also called angle-angle diagrams). The concept of cyclograms, although known to the biomechanics community, has not been seen very frequently in the literature of the recent past. The cyclograms we get by very easy way. Because cyclograms are graphs of angles, there are more kinds of cyclogram we can plot, for example angles between knee and ankle and so on (Fig. 8). We can decide which kind of cyclogram is applicable for our research and best for application in physiotherapy. The choice is cyclogram of knee and hip, because measuring of angles in this joints is easiest and the most accurate as well. Our proposed model also allows the determination of the 3D trilateral cyclograms (Fig.8). The our model in MatLab allows us to evaluate the length of the trajectory, instantaneous speed and acceleration, and ultimately allow us to compare three angles, such as ankle-knee-hip for left and right side of human body.

During the clinical measurement the measured data are grouped according to age groups and diagnoses of patients. Main create cyclograms of angles, velocities and acceleration are the following: left knee - left hip, right knee - right hip, left hip - right hip, left knee - right knee, right shoulder - right hip, left shoulder - left hip. Furthermore, we could study these characteristics of cyclograms: the length of trajectory, frequency of loops, slope, maximum range, average speed, total circumscribed area, and try to identify the typical characteristics associated to patient's diagnosis. The main objective is to propose methodologies for evaluating the patient's disability on the basis of determining the characteristics of these mentioned cyclograms. For this reason, we are interested in study a typical cyclogram and relationships its important features to the characteristics of the normal gait or gait of disabled patients.

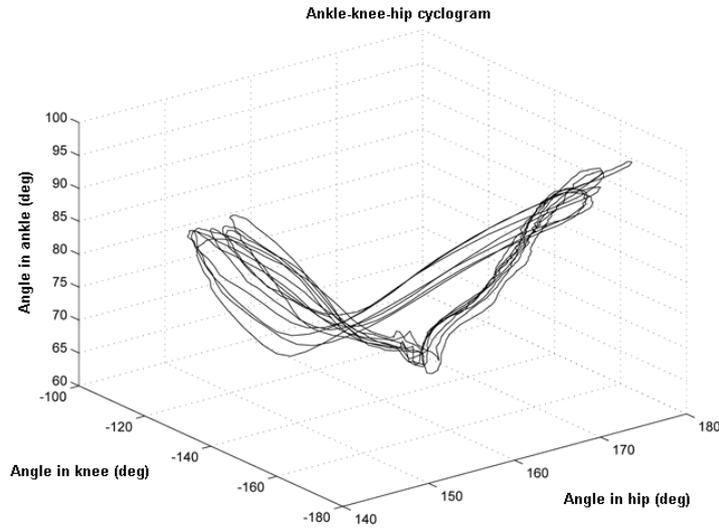


Figure 8: Trilateral cyclogram of leg movement

One of the main parts of the model is possibility to determine force conditions during movement of the human body, especially during walking. The force is generally defined by Newton's second law of force as the result of acceleration and mass of material of object. Our model contains 16 segments with a defined mass and moment of inertia. The segments are connected by 13 joints.

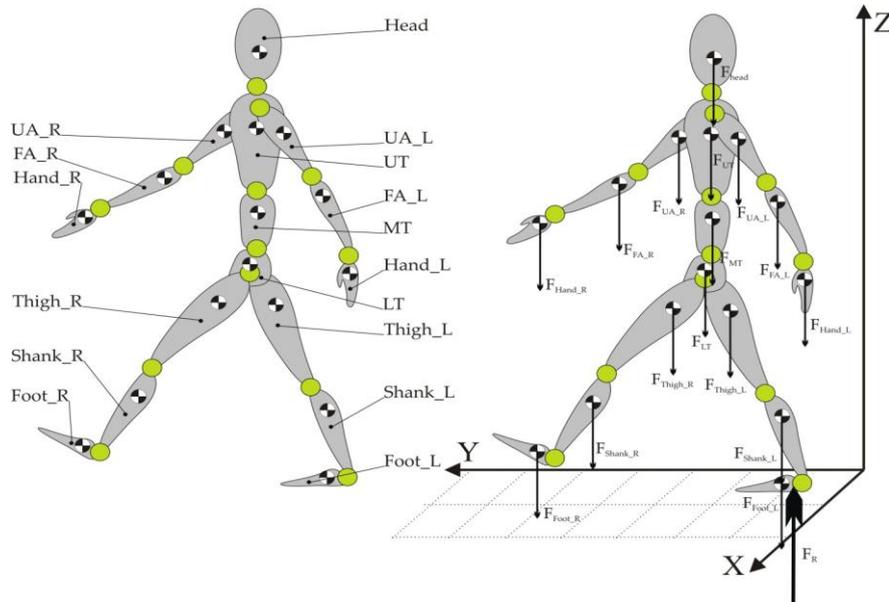


Figure 9: Segments and their weights, which are used to calculate the size of forces in the joints.

The equation for calculating the components of forces acting in the Z axis in the center of gravity of the body Foot\_R would look as follows:

$$\vec{F}_{Foot\_R\_z} = (m_{Foot\_R} \cdot \vec{a}_{Foot\_R\_z}) + (m_{Foot\_R} \cdot \vec{g}) \quad (2)$$

where  $F_{Foot\_R\_z}$  is the resulting force in the Z axis of the right foot, the weight of segment is  $m_{Foot\_R}$ , which in this case is weight of foot, the translational acceleration of the segment in

the Z axis is  $a_{Foot_{R_z}}$  and  $g$  is the gravitational acceleration acting on the axis. By this way we proceed in the calculations for all segments of the body.

Now we have obtained the forces acting in the center of gravity of the all segments and we can now proceed to figure out the forces acting on the joints. The calculation procedure we will describe by forces in the Z axis and for example for the forces in the knee. The calculation will be different if the leg is in swing phase or stance phase. Load at the knee during the swing phase is affected by forces in the ankle. This is why we have to add up all the component forces on the Z-axis, i.e. forces applied to the ankle and shank in the center of gravity. Identical procedure we use to calculate the load on the hip and so on.

$$-\vec{F}_{Ankle_{R_z}} = (m_{Foot_R} \cdot \vec{a}_{Foot_{R_z}}) + (m_{Foot_R} \cdot \vec{g}), \quad (3)$$

$$-\vec{F}_{Knee_{R_z}} = \vec{F}_{Ankle_{R_z}} + (m_{Shank} \cdot \vec{a}_{Shank_{R_z}}) + (m_{Shank} \cdot \vec{g}), \quad (4)$$

$$-\vec{F}_{Hip_{R_z}} = \vec{F}_{Ankle_{R_z}} + \vec{F}_{Knee_{R_z}} + (m_{Shank} \cdot \vec{a}_{Shank_{R_z}}) + (m_{Shank} \cdot \vec{g}). \quad (5)$$

As we already mentioned the approach to the calculation of the stance phase is different from the swing phase. During stance phase are all gravitational forces carried by lower parts of body. The parts of leg then carry the whole weight of the body segments and are added or subtracted forces caused by acceleration of each segment. The method of calculation is outlined in the equations:

$$\vec{F}_{Ankle_{L_z}} = \sum F_{all_z} - \vec{F}_{Foot_{L_z}}, \quad (6)$$

$$\vec{F}_{Knee_{L_z}} = \sum F_{all_z} - \vec{F}_{Foot_{L_z}} - \vec{F}_{Shank_{L_z}}, \quad (7)$$

$$\vec{F}_{Hip_{L_z}} = \sum F_{all_z} - \vec{F}_{Foot_{L_z}} - \vec{F}_{Shank_{L_z}} - \vec{F}_{Thigh_{L_z}}. \quad (8)$$

The  $F_{Ankle_{L_z}}$ ,  $F_{Knee_{L_z}}$  and  $F_{Hip_{L_z}}$  are resultant forces for individual joints in the Z axis (for example ankle, knee and hip of the left side of human body). The sum  $F_{all_z}$  represents the sum of all forces in the centers of gravity of the segments in the Z axis. From the values are subtracted forces which are characterizing the joint segments to which relate.

The next step in determining the resultant force vector in 3D space is just use of the resultant components of the forces that we calculated in the previous step. The calculation uses a simple Pythagorean theorem for three dimensional space.

$$\vec{F}_{Knee_L} = \sqrt{\vec{F}_{Knee_{L_x}}^2 + \vec{F}_{Knee_{L_y}}^2 + \vec{F}_{Knee_{L_z}}^2}, \quad (9)$$

where  $F_{Knee_{L_x}}$ ,  $F_{Knee_{L_y}}$ ,  $F_{Knee_{L_z}}$  are components of force at, for example, the left knee and the  $F_{Knee_L}$  is resultant vector forces at the knee. The size of this vector characterizes the load on the knee, which is transmitted in this case by the meniscus.

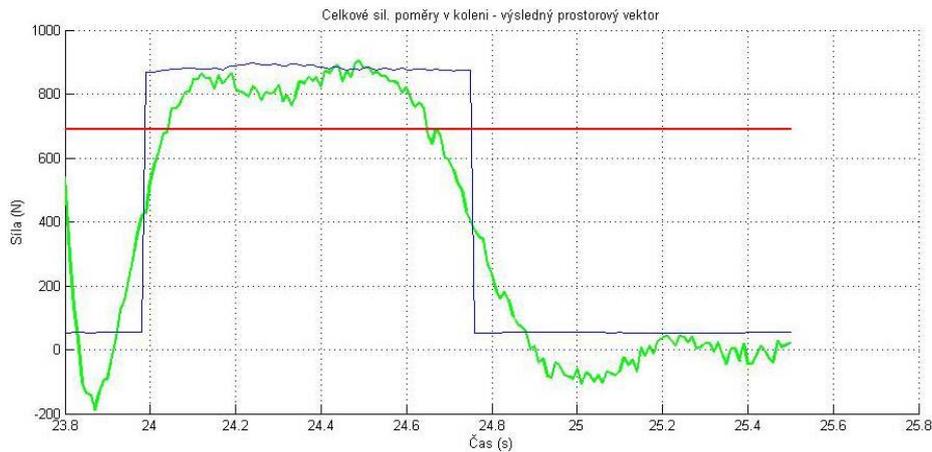


Figure 10: Graphical output from the model - graph showing the change in the size of the total force at the knee.

In the same way we will calculate the resultant forces in the other left and right joints. Calculation of moments of forces during walking in the body parts, i.e. legs, is similar to the calculation of forces. The rotation around an axis of segment and the physical characteristic of the segment define the size and direction of vector of torque. The resulting sizes of moments are given by moments of inertia and angular accelerations of segments, and are mainly influenced by calculated forces in joints, and the instantaneous angle of turns of the segments and size of the segments. From this reasons, calculation of the moments of forces related to the axes X, Y and Z. And from these moments relating to the axes are then determine the total vectors of torques in the joint.

### 3. Results

The main objects of our study are cyclograms. By means of designed model we get graphs of changes of angle per time in all main parts of lower part of human body. It is important for subsequent computing of cyclograms in the same model. These graphs are plotted from data which was obtained during measuring by motion capture system Lukotronic AS 200. From the graph ensue that the angle in knee is usually changing from  $2^\circ$  (stretched leg) to  $79^\circ$  (shrugged leg), where the value of angles represented angle between femur and shin. From cyclogram we know that typically the swing phase starts at  $0^\circ$  thigh extension angle and a knee flexion of about 80% of the maximum.

### 4. Conclusions

We designed method and model for evaluation of human walking in neurological and physiotherapy practice based on evaluation of angles and forces in joints. We designed user interface in the MatLab and the users can easily handle all parts of our program. This interface for work with our application allows analyze graphs of measured data, it is angles per time, bilateral and trilateral cyclograms. Further, the body model allows animation of motion and the identification of the forces and moments of forces in joints of body parts. Body model is modifiable by changing of weight and moments of inertia of whole human body or only the segments, from which we can count the moments and forces in joints. It could be important to study during which movement and in which part of movement is joint most loaded. In the next step of our research is clear to apply the designed model to research of hydraulic or pneumatics prosthesis.

## Acknowledgment

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