VIRTUAL 3D HUMAN MODELLING AND DIGITAL BIOMECHANICAL ANALYSIS

The researches have been conducted of digitaly given anthropometrical measurings and threedimensional dynamical changes of biomehanical characteristic of people from croatian population. By methods of scientific visualisation on virtualy generated statical 3D humanoid models the investigation has been done of various characteristics of the human beings, and how different parts or organs of an organism work together to achieve a particular function. Through computer animation of dynamical 3D virtual models, the digital biomehanical analysis of human spatial propulsion has been made, based on distribution of mass centres during motion. The work is concluded with some modest ideas of future possibilities in the field of human digitisation, modelling and animation, as for example is the development of different new kinds of biomechanical models on a structure and function of the locomotive system of the human beings, involving anatomy, physiology, anthropometry and cybernetics.

Key words: virtual 3D biomehanical character, anthropometry, biomechanical analysis

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1. Introduction

Biomehanical analysis of mechanism of human motion is very complex and demanding, regarding which the authors have made meaningful the new approach of computer visualisation and scientific analysis of virtual 3D characters. Developed virtual 3D models of computer kinematic and locomotory system as one of a man, distinguish by digitalised statical and dynamical characteristics which reflect real human characteristics. Based on cognition of structure and functions of inner kinematic system of human body, computer kinematic model has been made, which serves as an originating base for construction and animational analysis of virtual 3D character [1].

Within existing and available literature there is a large number of research descriptions when forming work places, which are often, besides their great pitoresqueness and with all thier logical anthropometrical correlation, not on the track of calculating human effort, i.e. reviewing difficulty of work. For example, from anthropometrical analysis of movement volume, what can often be found in the literature connected with the problem of forming work places, defined spatial dimensions and description of extremity reach come out, and very often data of eventual comfort or uncomfort are quoted. But from such data it is not possible to see any numerical indicators about power magnitudes or their lasting and reaction of the human body to them.

Biomechanical theory of the human or animal motion mostly is based on experiments in the course of we are measuring, places, velocities, accelerations, forces e.t.c. As the roof to data determined on this way in many attemptions was applying of different mathematical or mechanical methods. But, if an individual repeats a specific motion under almost similar conditions a certain numbers of times, the pattern of motion will be change in a particular manner. Partially if this repetition is aimed to learn the optimal motion for a certain specific kind of motion.

2. Biomechanical Anthropometry

Fundamental measures in the movement description are anthropological measures. Practically, in the so called "biological anthropology" (or may be “physiological anthropology”) we consider only statical anthropometry, that is content about data on linear measures like the distance between two emphasized points on the body. Also in this group of data there are angles of the relative motion of the body parts, which we can call kinematical datas. Under the term "biomechanical anthropometry" we don't understand only the linear measures like above mentioned distances between two emphasized point, but here we include the segmental masses and their distribution referently to chosen coordinate system, then dynamical moments of inertia reduced to the centres of gravity of each segment, and then reduced to the centre of gravity of whole body. Further, what is very imortant to know that emphasized points for the same segmental part are not of the same value. In dynamical anthropometry the emphasized points are centers of instantenous relative rotation inbetween two neighboring members. Also in biomechanical anthropometry are of particular attention knowing a time function of this quantities [2].

We divide dynamical anthropomeasures into internal and external. Dynamical moments of inertia that are determined by means of outside borders of the body segments are external dynamical moments of inertia. Related to the internal masses distributions, during some relative motion between the body segments, different quantity of the muscles and bone masses are involved in motion comparing to that what we can see from the outside. Even, by internal dynamic measures the masses of the muscles are depend about a relative motion and the time. A typical example could be motion of the arm of standing person. If the arm hangs freely then one group of the muscles belongs to the volume of the arm according to the outside borders. If arm moves to upstairs then in motion increasingly is involved a group of brest's and back's muscles together with shoulder blade. So we have motion of the system with the changable mass during the motion. As we know internal dynamical moments of inertia are not yet enough investigated.

2.1. Harmonic anthropometrical analysis

Based on general results of harmonic analysis which are implemented on man and which have been shown as functions of anthropometrical magnitudes in relation with man's standing hight, Muftić's contemplation showed out that for defining ratio of body parts lenght so called harmonic circle is used. For the mentioned anthropometrical analysis greek canon of eight head lenghts is being used, which points that total human body hight shown equals sum of his eight head lenghts.

In case that this canon is joined to haromonic circle the grid construction is possible which shows contour limits of man, as shown on figure 1. With that, canon of eight head hights is joined with Zederbauers harmonic circle. Considering this values, as well as the assesment of position of joints of knee, hip, shoulders and elbows, it was possible to draw into in the figure 1 grid, characteristic points A, B, C, ... By doing so, drawing into linking lenghts, auxiliary skeleton of a man has been drawn, so called stick model, as shown within the figure 2.

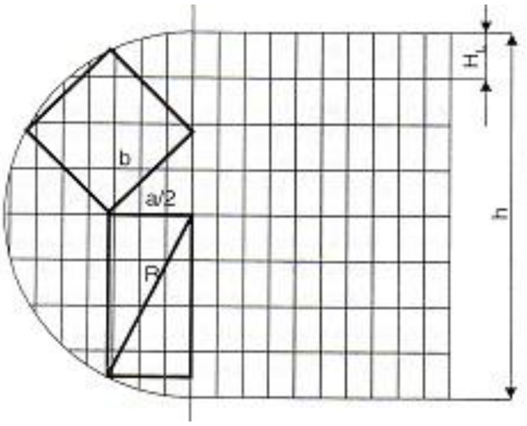

Fig. 1. *Harmonic circle with associated grid of eight head hights canon*

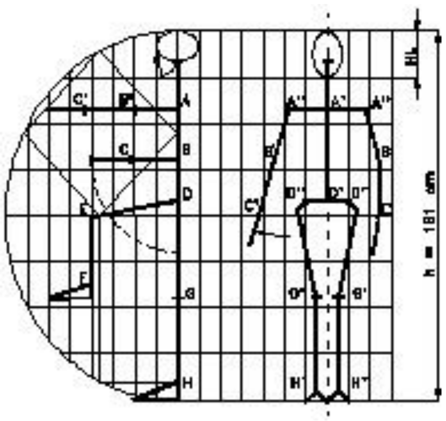

Fig. 2. *Harmonic circle with plane model of geometrical human skeleton*

After drawed into contour according to photography of measured subject, appropriate anthropomeasures have been measured, both on the drawing and on the subject. Muftić and Baksa have developed new computer method of determinating anthropomeasures from body prints which were put into computer, figure 3.

Further step is related to harmonical analysis of the mass distribution of external segmental body parts comparing them to the whole body mass [3]. From this analysis comes out that the mass distribution for a normally developed adult males as well for females follows harmonical number with relatively great accuracy. It so close, that we can say, that the anthropometrical values of linear lengths as well segmental masses harmonical values. So, in this manner it is credibly to state segmental masses of body parts, as percentage of total body mass. Furthermore, according to the results of Dempster, Donskij and Zacijorskij, figure 4 has been made, on which beside segemental masses positions and gravity centres of segments have been determined, expressed in percentage of segments lenght [4].

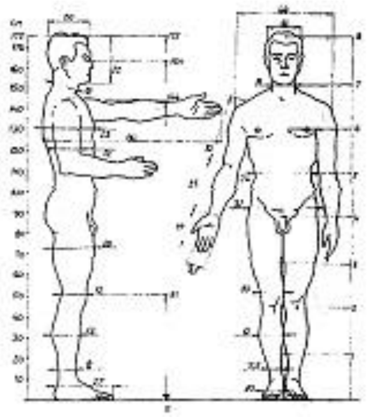

Fig. 3. *Male subject with associated measures*

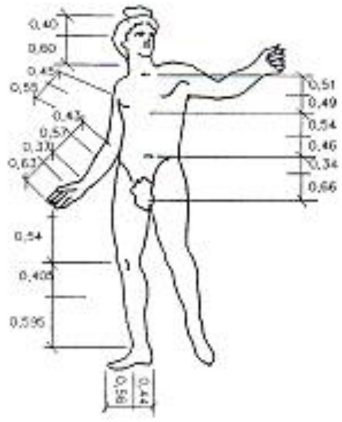

Fig. 4. *Relatively position of mass centres of human body parts*

2.2. Automatic determination of anthropometric measures

Conventional determination of anthropometric measures for each individual, employing conventional methods, is a complex and time-consuming job. New computerised methods offer fact and accurate determination of all the key bodily measures. A software application "*ErSABA*", (*ERgonomy by SArajko BAksa*), has been developed, of the 4.2. version at the moment, which can, using the input data on body height, weight and gender, together with the necessary accuracy of position at work, determine 22 characteristic anthropometric measures [5].

Figure 5 shows a pictorial and alpha-numerical on-screen presentation of characteristic anthropometric measures for a standing male person, while the Figure 6 shows alpha-numerical on-screen view of the whole of the characteristic anthropometric measures for the person measured. Measuring data are at the moment available for the persons that are actually measured and for those that know their height. After processing, the anthropometric data are automatically stored into so-called anthropometric database, so that they are available for further "off - line" analyses [6].

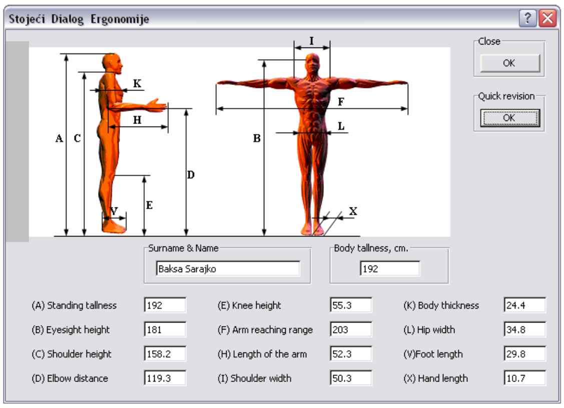

Fig. 5. *On-screen presentation of characteristic anthropometric measures for a standing male person*

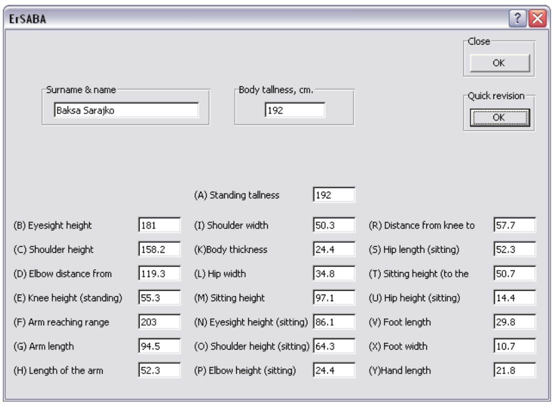

Fig. 6. *On-screen view of the whole of the characteristic anthropometric measures for a male person*

2.3. 3D Digital Body Capture and Measurement System

Most investigators, in constructing a geometrical model of a human body, focus on the procedure of taking a series of surfaces bordered with co-ordinate points of a 3D measuring cloud, obtained by modern 3D scanners. The procedure offers precisely the same model of the bodily construction of the person, associated with a particular dotted cloud, and describing bodily measures of a particular character. The whole of the construction of the virtual human model is based on knowing the volume and cross-section of the body, as well as its mechanical behaviour in the performing dynamic movements [7].

SABA*Lab* has developed and offered a three-dimensional digital body scanning with 3D Body Measurement system, "*BodySABA*" of the actual version 0.3., Fig. 7. Body Capture System "*BodySABA* 0.3." is in an initial phase of its development. However, as can be seen at the digital 3D presentation in Fig. 8., its applicability even in its present form is quite obvious for contemporary CG techniques of digital scanning.

Fig. 7. *Scanning with digital Body Capture System "BodySABA 0.3."*

Fig. 8. *Digital 3D presentation of the object scanned*

Body Capture System "*BodySABA*" is intended for spatial 3D scanning of objects, with the purpose of constructing virtual 3D models. The system can be used for garment and footwear design, garment and footwear industry, car industry, development of video games, construction of virtual bodies, creation of internet-oriented characters, doing business on the Internet, anthropologic research, ergonomic studies, healthcare applications, sports analyses etc.

2.4. Motion Capture System

To give successfully an illusion of personality, life, emotions and personal character to virtual 3D actors, employing animation methods and procedures, it is necessary, besides possessing certain amount or artistic sensibility for character animation, to study thoroughly and with understanding the biomechanics of man resting and in movement, as well as movements of other living systems. The problems of mechanics of movement of living systems are highly complex, especially so for men. Complexity is exhibited in sorting biomechanic samples, as well as in their analysis and movement synthesis, when movability and control of the system investigated (or group of systems) should be defined at the same time.

Conventional approach to the animation of 3D characters includes the animation of key frames. It yields high quality animation results, but the procedures employed are time consuming, which means that production is rather expensive. More modern and highly popular approach is based on the implementation of the so-called "Motion capture (mocap)" system. These systems detect full macro body movements, as well as full 3D micro facial and hand motions and movements of real human actors. They also digitize real movements into corresponding behavior of virtual characters. Motion capture systems should be able to detect the movements of real actors, generate various reflections and ideas of virtual characters and translate real recorded movements of real actors to virtual humans in virtual environments. All the motion capture systems are characterized by their ability to store the data recorded for future analysis and processing.

SABA*Lab* motion Capture System "*VatoSABA* 1.4." for Computerised Movement Analysis digitises real human movements recorded into corresponding virtual 3D character behaviour. It is a new and original approach to computerised character animation of virtual 3D humans, offering both minimal investment and ease of work, as with key-frame animation, as well as accuracy and speed of automatic motion capture digital systems.

Figure 9 shows recording biomechanical movements of a real model, employing the *VatoSABA* 1.4. motion capture system in a movie studio. Figure 10 shows a section of a computerised virtual human figure animation, based on real behaviour of a real human model from the Figure 9, recorded using the *VatoSABA* motion capture system [8].

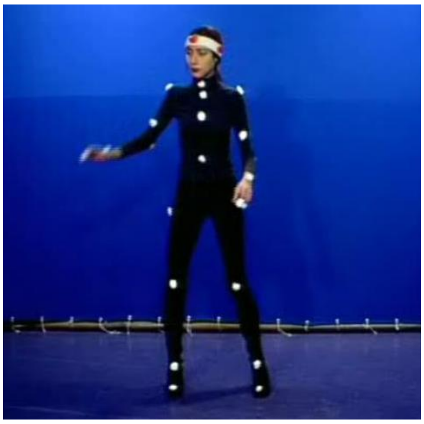

Fig. 9. *Studio recording with VatoSABA 1.4. motion capture system*

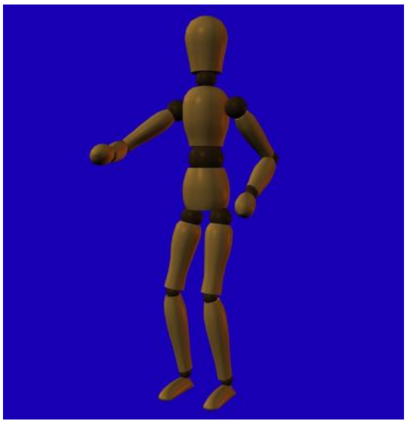

Fig. 10. *Section of a computerised virtual character animation based on the input data acquired by the VatoSABA 1.4. mocap system*

3. Spatial positioning of a man

If we place a man in threedimensional space, as shown on figure 11, then ratio of his body to sides of cube can be defined by coordinate order, whose axises are parallel with edges of cube. By introducing the idea of coordinate order or settlement at the same time we introduce ideas of plane, axis and point.

On the picture 11 usual symbols for axises x, y and z have been drawn into. To each pair appropriate plane has been joined, which results with planes xy, yz and zx. Arrows on the axises x, y and z show how individual values grow on the axises. Shifts in the same direction with arrows are positive, and if they are of opposite direction, then they are negative [1].

Considering that the coordinate settlement is applied to man we quote medical terminology which describes particular planes. Plane xy is called transversal plane; xz plane is called sagittal plane and yz plane is called frontal plane. Positive shifts from the point 0 in direction of positive x axis are called ventral and negative are called dorsal; positive shifts in the direction of positive y axis are called left lateral and negative right lateral shifts, and finally shifts from the point 0 in the direction of positive z axis are called cranial and negative are called caudal.

Special meaning of choice and agreement about marking the axises of coordinate order is present when considering rotation arround one of the axises. For the choosen coordinate system we say that it is right or Cartesian coordinate system. This is connected with the fact that change of the angle, when moving from x axis towards y axis in xy plane is considered positive. If from the x axis in the same plane xy the change of angle happens towards negative side of y axis, then the change of angle is negative.

4. Biomehanical models

Structural scheeme of human skeleton has very large number of degrees of motion freedom. Regarding that human skeleton consists of 95 joints with one degree of motion freedom, 80 joints with two degrees of motion freedom and 75 joints with three degrees of motion freedom, which is in total 250 degrees of motion freedom, all complexity of kinematic and dynamic study of human skeleton can be understood. Some authors quote different degree numbers of motion freedom of normal skeleton, from 240 to 300. This is significant because mobility of computer 3D model depends on number of degrees of motion freedom of his constructive elements. Biomehanical model should clasp as many number of degrees of motion freedom and with its characteristics to simulate real condition as good as it can. The model of kinematical chain suits it best, in which joints are connections between particular model segments. Great influence on the accurance of analysis and simulation of motion have geometrical and inertial characteristics of body segments.

Generally, with respect of mentioned suppositions and simplifications, bodies of virtual biomehanical models are formed with 16 geometrical rigid bodies connected with joints. Body is divided on segments with planes vertical on the longitudional axises of segments, in the manner formed by Donskij and Zacijorskij [9], which enabled use of their data for determination of the mass centres positions of body segments and regressional equations for determination of segmental masses.

Head and neck are considered as one segment, and from upper part of body they are separated with plane vertical on longitudional head axis which passes through throat hole (suprasternal). Body is divided in three parts – upper, middle and lower part, namely thorax, abdomen and pelvis. The plane which presents border between thorax and abdomen passes through the tip of thoracic bone, and abdomen and pelvis are separated with the plane which passes through navel. Pelvis streaches out from navel to hip joints. Segments of lower and upper extremities are determined by division of limbs in joints by planes vertical on longitudional axises of segments. Upper leg streaches from hip joint to knee joint, lower leg form knee to ankle, and ankle presents border between lower leg and foot. Arm is divided on upper arm, forearm and fist with borders in shoulder joint, elbow and fist joint.

The first digital biomechanical model has been developed SABA*Lab* for the needs of the Croatian fashion industry, to be used in the first Croatian virtual fashion show, Fig. 12. The virtual model has been developed using I. Baksa, a real model, as a basis, and contains all the relevant characteristics.

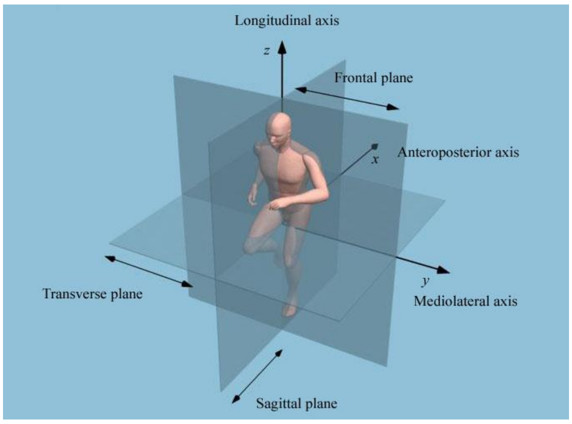

Fig. 11. *Basic planes and directions of human virtual body*

Fig. 12. *Frame of a 3D Modeling with Catwalk presentations*

5. Determination method of the change abdominal pressure

By observing the changes of pressure in abdomen of a man it is possible to define its biomehanical exert during working procedures, and as critical body niveau side spine is taken, namely spinal disc between 4. and 5. side vertebra, marked as point L4/L5. Studies have shown that intraabdominal pressure (IAT) raises depending on increase of so called lumbal moment. For determination of body postures, corresponding reactions in workers muscles and bone system occur, and specially in abdominal area, which reacts by increase or decrease of inner pressure. The inner pressure acts forward towards abdominal muscles, backwards into the spine and lumbal muscles, upward towards diaphragm and downwards towards the bottom of pelvis. The effect of forces of the inner pressure in a man who lifts burden, in skeletal presentation is given in figure 13 [10].

Biomehanical models for calculating the lumbal moment are divided in two shapes: twodimensional and threedimensional models. On the picture 14 twodimensional model is shown, positioned into coordinate system xz, in which referal position of vertebras L4/L5 in starting point 0, and appropriate anthropomeasures are marked with appropriate letters.

Fig. 13. *Presentation of intraabdominal pressure in a man lifting weight*

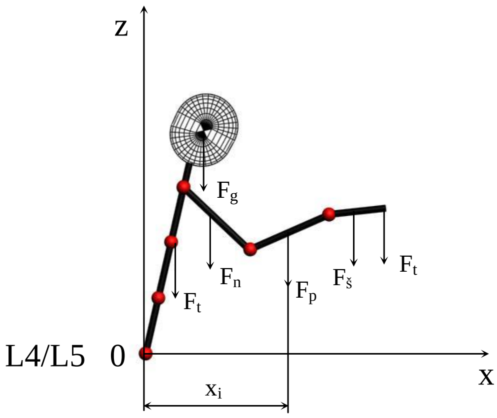

Fig. 14. Twodimensional model of examinee

The analysis of this procedure starts with the data input about certain positions of characteristic, in advance determinated points of human body in motion. The facts about positions of jointed points have been taken with the use of the "Motion Capture" program solution “*Vato*SABA” sequentialy from the motion pictures of the body propulsion during work.

Based on such established facts of coordinates of marking signs, from SABA*Lab*, the computer program has been created for calculating the centres of masses segments of the body as well as common body centres of the masses “*MaSABA*”. From such determined facts the line form of computer animated inner skeleton structure of measured subject has been established, figure 15 [1].

6. 3D visualisation

Making of threedimensional modeling, design, animation and visualisation is done on graphical work stations, using more different 3D graphical-animational program packages. Based on photographed worker and working place in some technological process, computer 3D model of the worker, working elements and working place is made.

According to real data on given computer generated 3D scene, by methods of scientific visualisation, SABA*Lab* is capable to do virtual 3D biomehanical analysis of working moves of the workers body.

3D model of worker, working elements and working place make 3D scene, by which one considers in computer graphics oriented part of space, to whom coordinate system is joined, in relation to which the position and orientation of entities, primitives, objects or their groups. Figure 16 shows perspectively display of simulation stick model of medical personel on working place.

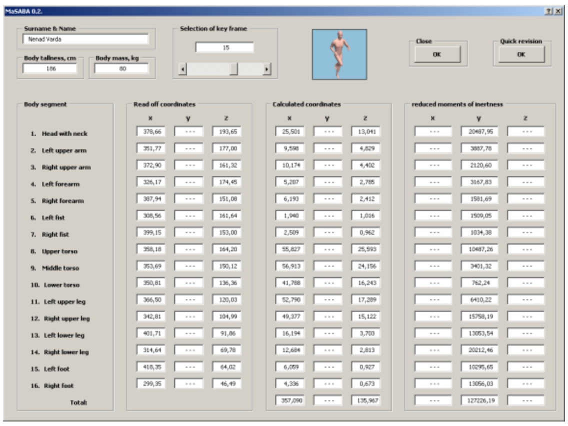

Fig. 15. *Screen display of program application “MaSABA”*

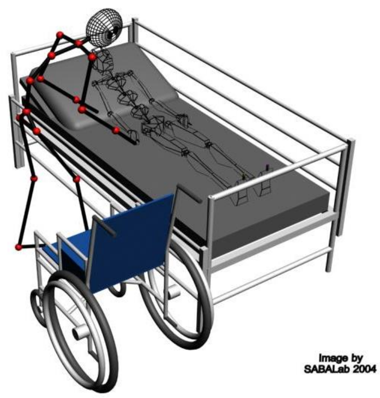

Fig. 16. *3D visualisation of working process of medical personel*

With the use of existing real or computer performed maps and materials, and with processing their parameters like colour, radiance, illumination, transparency, relief etc., it is possible after conducting more complex procedures of rendering to get very real, i.e. photo-realistic results of virtual space of working place or worker.

7. Future Work and Conclusions

Accoding to actual stage of development of computer technique, the results of harmonised anthropodynamical characteristics will be determined in the framework of adequate knowledge bases, which will be component of one general ergonomical expert system. Within the frame of such subsystem it will be, for instance, possible based on programatic settled video recording to conduct adequate biomehanical analysis of any kind human body effort, classified, diveded values to appropriate statistical division of determined domestic and world population.

In analysis of man's motion, or for relatively motion of body parts with great accelerations, one needs to know forces and moments or speeds and accelerations of particular body points, then knowledge of position of mass centres and dynamic moments of inertia of both segments and whole body in the moment of observation.

Observing body parts of various masses and dimensions as parts of kinematic chain, and analysing various position of standstill and motion with the biomehanical point of view, it is possible to find out most favourable kind of motion within some technological process and so prevent unneccessary exhaustion or illness.

With further development of computer program applications *ErSABA*, *BodySABA*, *VatoSABA* and *MaSABA* further progress of automatic determination of anthropometrical and ergonomical characteristics of biomehanical models of real and digital acters will be enabled, and better connection of anathomic and psycho-physiological researches of human body based on threedimensional virtual simulations and analysis of virtual characters.

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