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DESIGN OF THE 3D MODEL OF HUMAN BODY ORIENTED TO BIOMECHANICAL APPLICATIONS

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1. Introduction

The knowledge of geometric and inertial characteristics of human body is very important in ergonomical studies and biomechanical analyses where a long-standing problem is absence of practical method of obtaining static and dynamic anthropomeasures' data.

There are a number of experimental techniques for determination of inertia parameters of human body. The shortcomings in inertial property estimations using cadaver-based prediction methods have led to developing methods for measuring inertial properties directly on living subjects. Methods that have been investigated to date are photogrammetry, gamma mass scanning, mathematical modelling and computerised tomography (CT).

The aim of this work was to determine the 3D biomechanical model of human body and practical automatised method that will permit the determination of static and dynamic anthropomeasures by directly measuring subjects. Because in accessible literature there is a little existing data of dynamic moments of inertia of body segments for women, in this work research was done for female subjects.

2. Methods and subjects

2.1 Biomechanical model

The biomechanical model has to include the grater number of degrees of freedom, to better simulation of really situation. In order to achieve this goal, the most suitable model is a model of kinematics chains, where body segments are connected with joints.

To determine inertial characteristics, the model of body as sticks connected by joints is not convenient. More capable for inertial characteristics' calculation is modelling of subject's body segments by geometric solids.

Model that represents the body segments using a number of geometric solids is based upon simplifying assumptions, such as a uniform density over a cross-section and along longitudinal axis of the segment. Nonrigidity of the body segments is neglected. We suppose full body symmetry with respect to the medial plane, i.e. a complete "left-right" symmetry. For calculation of inertial characteristics, the values for left and right limbs are averaged to have symmetrical values.

The body is modelled using 16 geometric solids which are connected by joints. The body is sectioned into geometric solids by planes perpendicular to the longitudinal axes of the segments.

Head and neck represent one segment, which is sectioned from upper trunk by plane passing through the lowest point of the jugular notch of the sternum (suprasternale) and which is perpendicular to the longitudinal axis of the head. Trunk is sectioned into three segments: upper trunk (thorax), middle trunk (abdomen) and lower trunk (pelvis). Boundary between upper and middle trunk passes through the junction between xiphoid process and the body of the sternum. The lower trunk is bounded by transverse planes through umbilicus and hip joints. Upper and lower limbs are sectioned into three segments by transverse planes in neighbour joints (shoulder, elbow, wrist, hip, knee and ankle).

Because the manner of sectioning body into segments is the same as by Donsky and Zatsiorsky [Donsky, Zatsiorsky 1979], their regression method for determination of body segments mass and locations of mass centres of segments is used. The shape of geometric solid which represents body segment, depends upon body segments shape and location of mass center. Volume of any particular segment can be determined from calculated segment's mass and segmental density value [Dempster 1961] Some linear dimensions of body segments are measured and other are determined from calculated volume and known position of mass center of segment.

The solids representing the head, arms and legs are assumed to be of circular cross-section. Head and the neck are modelled as an ellipsoid. It is necessary to measure only longer axis of ellipsoid, i.e. distance from top of the head to jugular notch. Smaller axis of ellipsoid can be calculated from volume.

Upper arm, forearm, thigh and leg are modelled as a frustum of cone. The frustum of cone is defined by measuring length of segment and calculating upper and lower base radii from known volume and location of mass centre.

The simplified approach is adopted that neglects positions of hand center of mass and models the hand as an elliptical plate. Semi-axes of the elliptical plate are measured and thickness is calculated from volume.

The foot is modelled as a parallelepiped with cut three-sided prism. Height and width of parallelepiped are directly measured, and lengths of prism and parallelepiped are calculated from volume and location of centre of mass.

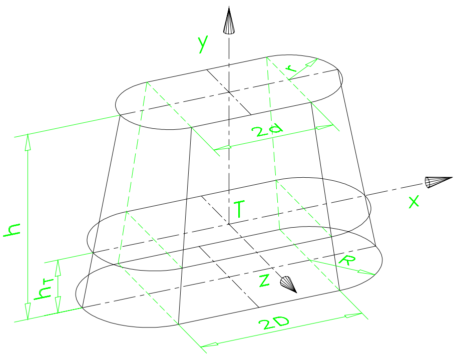

Figure 1. A "stadium" solid

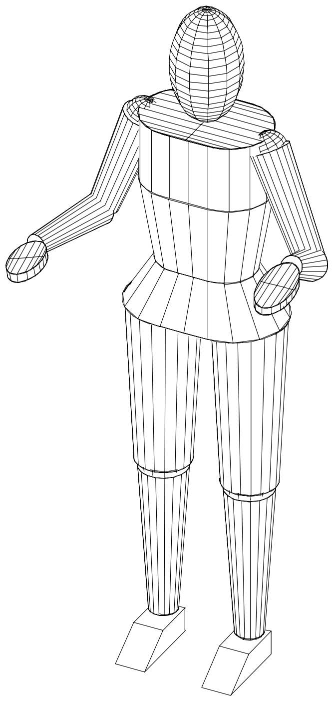

Figure 2. Female body modelled by 16 geometric solids

A “stadium” solid is introduced for modelling torso segments. A “stadium” is a rectangle of width $2d$ and depth $2r$ with an adjoining semi-circle at each end of its width. A “stadium” solid bounded by two parallel stadia is shown in Figure 1.

Upper trunk is modelled by solid bounded by two parallel stadia of same dimensions. The width of the base ($2r + 2d$) is a distance between the shoulder joints and is measured directly. The height of the upper trunk, i.e. distance between plane through jugular notch and plane through xiphoid process, is directly measured. Using calculated volume and width of the base, it is possible to determine parameters r and d of upper trunk. These parameters are parameters r_1 and d_1 of the upper base of middle trunk, too.

The height of the middle trunk is directly measured as a distance from xiphoid process to umbilicus. From known volume and location of center of mass, the parameters R_1 and D_1 of the lower base of middle trunk can be calculated. Parameters R_1 and D_1 represent parameters r_2 and d_2 of the upper base of lower trunk.

The height of the lower trunk is measured and parameters R_2 and D_2 of the lower base are determined from volume and location of center of mass.

Female body modelled by 16 geometric solids is shown in the Figure 2.

Central dynamic moments of inertia of geometric solids which represent body segments (i.e. rotational ellipsoid, frustum of cone, elliptical plate, parallelepiped, three-sided prism and “stadium” solid) are calculated using the equations from literature [Bazjanac 1974, Meriam 1971].

2.2 Measuring

The measuring procedure comprises recording of the marked female subjects aided by the measuring system ELITE. The system ELITE consists of two infrared (IC) cameras that can detect infrared light reflected from the markers and a program that computes 3D-coordinates of the markers relative to a fixed co-ordinate frame.

Markers are placed on characteristic points on subjects according to defined biomechanical model. Markers are attached on joints and on the points important for determination of segments dimensions and orientation in global co-ordinate frame. Segments dimensions are calculated as a distance between the markers placed on characteristic points.

If the segment is represented by rotational symmetrical solid, the axis of rotation is principal axis of inertia and it is enough to attach only two markers on the segment. Axis of rotation represents y_i-axis of local co-ordinate system (x_i, y_i, z_i) with origin in mass center of segment.

If the segment isn’t rotational symmetrical (e.g. hands, feet, and trunk), three markers are needed to determine orientation of segment. Local coordinate system of trunk segment is shown in Figure 1.

24 markers are attached to the characteristics points of subjects body (Fig. 3) on the following manner:

- marker 1 - top of head,
- marker 2 - suprasternale
- marker 3 - right shoulder joint
- marker 4 - right elbow joint
- marker 5 - right wrist joint
- marker 6 - base of thumb (right hand)
- marker 7 - middle finger (right hand)
- marker 8 - left shoulder joint
- marker 9 - left elbow joint
- marker 10 - left wrist joint
- marker 11 - base of thumb (left hand)
- marker 12 - middle finger (left hand)
- marker 13 - xiphoid process
- marker 14 - umbilicus
- marker 15 - right hip joint
- marker 16 - right knee joint
- marker 17 - right ankle joint
- marker 18 - base of great toe (right foot)
- marker 19 - left hip joint
- marker 20 - left knee joint
- marker 21 - left ankle joint
- marker 22 - base of great toe (left foot)
- marker 23 - base of little toe (right foot)
- marker 24 - base of little toe (left foot).

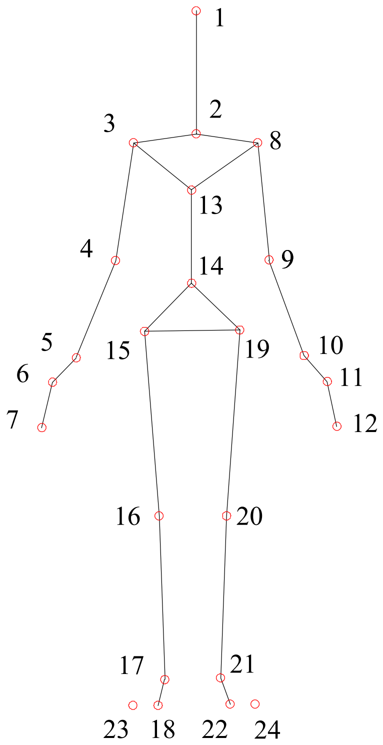

Figure 3. Body model of markers connected with lines

The same person has attached markers on all subjects for the reason that mistakes of marker placing will be reduced. Measuring has been performed on 120 women of Croatian population between the ages of 19 and 30 year (mean age 24.2 year).

The female subjects are recorded in upright standing position. The ELITE graphical representation of subject's model in sagital and frontal plane is shown in Fig. 4.

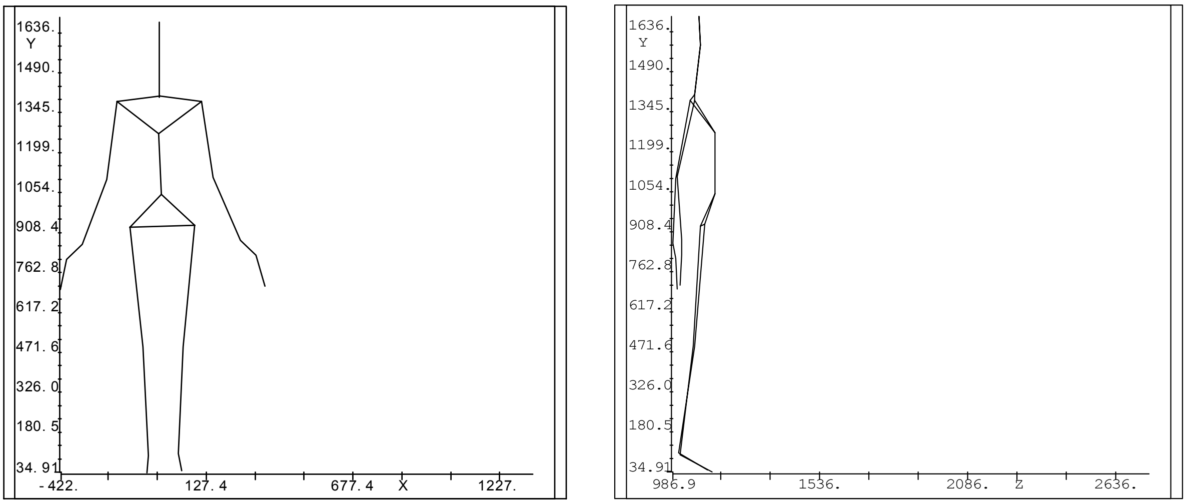

Figure 4. Graphical presentation of the model in frontal and sagital plane

The software of the system ELITE has been widened by the program written in Matlab which, by means of recorded 3D co-ordinates of the marked points, calculates segments mass, volume, dimensions, centre of mass and central dynamic moments of inertia for all three axes of local co-ordinate systems (x_i, y_i, z_i).

3. Results

The main static anthropomeasures and central dynamic moments of inertia of body segments are calculated for every recorded female subject. The obtained results are statistically analysed and divided into five percentile groups (tables 1, 2, 3, 4).

Table 1. Percentile distribution of static anthropomeasures, mm

Anthropomeasure	Percentile				
	5	25	50	70	95
Height	1564	1626	1669	1703	1774
Length of upper arm	258	276	288	297	318
Length of forearm	228	240	249	256	270
Length of arm	646	677	699	716	752
Length of thigh	357	381	398	411	439
Length of leg	760	808	841	867	922

Table 2. Percentile distribution of central dynamic moments of inertia I_x of body segments, gm^2

Segment	Percentile				
	5	25	50	70	95
Upper trunk	28.5	38.1	44.4	51.4	62.1
Middle trunk	29.3	39.5	49.0	56.4	70.1
Lower trunk	22.5	28.0	31.3	35.3	40.5
Head	23.1	25.0	27.8	30.1	33.0
Upper arm	8.3	9.2	12.2	14.0	16.1
Forearm	3.1	3.5	4.0	4.8	6.3
Hand	0.539	0.623	0.681	0.726	0.823
Thigh	90.1	105.2	151.1	181.0	215.3
Leg	24.0	30.5	36.0	40.0	48.1
Foot	1.2	2.1	2.5	2.9	3.8

Table 3. Percentile distribution of central dynamic moments of inertia I_y of body segments, gm^2

Segment	Percentile				
	5	25	50	70	95
Upper trunk	51.8	77.1	90.2	111.9	151.1
Middle trunk	40.6	62.1	72.0	83.3	103.5
Lower trunk	52.1	78.0	93.4	121.3	152.5
Head	12.3	13.2	13.9	14.9	15.8
Upper arm	1.10	1.30	1.41	1.46	1.71
Forearm	0.36	0.44	0.49	0.53	0.62
Hand	0.135	0.164	0.184	0.201	0.233
Thigh	15.9	20.6	28.2	33.9	43.0
Leg	2.9	3.5	4.1	4.4	5.0
Foot	1.5	2.4	2.8	3.3	4.3

Table 4. Percentile distribution of central dynamic moments of inertia I_z of body segments, gm^2

Segment	Percentile				
	5	25	50	70	95
Upper trunk	45.9	70.8	81.3	96.0	120.1
Middle trunk	45.6	69.1	80.1	92.8	114.7
Lower trunk	30.9	46.5	62.4	74.8	98.0
Head	23.1	25.0	27.8	30.1	33.0
Upper arm	8.3	9.2	12.2	14.0	16.1
Forearm	3.1	3.5	4.0	4.8	6.3
Hand	0.656	0.750	0.816	0.867	0.976
Thigh	90.1	105.2	151.1	181.0	215.3
Leg	24.0	30.5	36.0	40.0	48.1
Foot	0.42	0.51	0.73	0.82	1.10

Comparing the results in tables 1, 2, 3 and 4 with results of Rudan, Muftić, and Finch [Rudan 1978, Muftić 1989, Finch 1985], can be seen a small differences. This confirms that the method introduced in this investigation represents practical applicable method.

4. Discussion

A biomechanical model of female body and the method that permits the determination of static and dynamic anthropomeasures are described. This method has advantage in relation to existing methods because the measuring can be performed very quickly for every subject.

The automatised method established in this work represents a simple and practical applicable method of static and dynamic anthropomeasures determination. The model is able to produce reliable data which precision is sufficient for practical applications. The multibodysystem model can be commonly used for the dynamic analysis of human motions such as walking, jumping and gymnastic exercises. The model allows to perform both computer simulation and computer design oriented to ergonomic and biomechanical applications. Our aim for the further development of the model is to reduce deviations from the real human body trying at the same time to preserve the simplicity of the approximations used in the model.

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