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The Compact Formulation of Anthropodynamical Measures in Physiological Anthropology

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ABSTRACT

In this paper, an interdisciplinary combination of several state-of-art methods from biomechanics, modeling and multibody dynamics of the humans is described. The description of the human figure in the motion is a very important part of biomechanical analysis. In such current methods it is necessary to us mass moment of inertia as a part of the fundamental dynamic anthropomeasure when describing this motion. The goal of this work is to use and modify existing techniques and to investigate what have to be analyzed to make them work together. First, some general definitions and descriptions of mass moment of inertia adapted to anthropometric values of our population. Second, there is also a review of some simple models by means of which it is possible to calculate distribution of the body-part masses during the motion. The results are given in the form of equations and tables which present the functions between selected body parts anthropodynamical measures and percentile distribution values of males as well as females of Croatian population.

Introduction

Precise analysis of the human figure in motion in space is a very complex task. It is often complex also in those cases when many parameters are simplified. The reason for this complexity are numerous and particularly important in the formation of biomechanical models. This fact incited us to the elaboration of this work.

In the existing foreign and domestic literature available, there are lots of data on parameters of the human body dimensions[1–8]. In the mentioned sources, values of so called static anthropometry are predominantly pointed out. Liner dimensions of the body parts, namely the lengths of the body and it parts, are in them as well. Besides, on the extent of some typical motions of the body parts also appear in this literature and are taken as cinematic anthropomeasures[9,10].

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For some motions of a man or of some of his parts, in which significant accelerations or retardation appear, and, consequently, dynamic forces are increased, different room then in case of static or quasi-dynamic motion is necessary. For the analysis of such motions, that is for determination of forces and moments, mass distribution, positions of the masses of certain body parts examined (centers of masses) and finally dynamic moments of inertia should be known. The following problems how to calculate these values in the way they approximate some real situations.

If we divided the model in the Figure 1 into open cinematic chain introducing the symbols shown in the Figure 3, then we see that the motion of the member i, but only in the case that we assume the system as a whole is the result of forces (F_i) and moments (M_i). Equations of the planar motion of the mentioned member of the chain are:

$$m_i \, \bar{x}_{ci} = F_{x(i-1,i)} - F_{x(i,i+1)}$$

$$m_i \, \ddot{x}_{cz} = F_{z(i-1,i)} - F_{z(i,i+1)} - m_i \, g$$

$$J_{iS} \, \ddot{\varphi}_i = F_{x(i-1,i)} \, a_i \sin \alpha_i - \mathrm{F}_{z(i,i+1)} \, a_i \cos \alpha_i + F_{x(i,i+1)} \, b_i \sin \beta_i - \mathrm{F}_{z(i,i+1)} \, b_i \cos \beta_i + \mathrm{M}_{i-1,i} - M_{i,i+1}$$

In mentioned equations besides of translation and rotations of chosen points, there are the lengths of the members and their mass m, and at the end moments of inertia J_S.

Dynamic moment of inertia

Mathematical definition of the mass distribution about the instantaneous

ax of rotation is a geometrical relation according to Figure 2. done by:

$$J_x \quad \underset{m}{} \rho \;\, dm \ \mathrm{kg\ m^2}$$

where is the distance of the infinitesimal mass dm from the ax x.

Characteristics of some of dynamic anthropomeasures: External moment of inertia

To show the character of dynamic anthropomeasures, we shall examine one very simple example of planar human motion of the subject's body jumping. The scheme of some parts of this movement are given in Figure 1. From this figure it is clear that subject, besides translation, exerts some rotation as well. Provided that we choose for the models (as it is shown in the Figure 2) of body parts different cylindrical parts to be examined (arms and legs), elliptical parts (trunk) and rotative ellipsoid for the head, and if we calculate dynamic moments of inertia, that should be reduced to the gravity center using theorem of parallel translation, then we will have dynamic moment of inertia of the whole system to the chosen axis which is orthogonal to the paper. If we calculate now successively so-called average dynamic moments of inertia for the entire shown body configuration, we shall see that their value change depending on time. The general form of such dependence is shown by the diagram in Figure 1.

Materials and Methods

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 mass 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

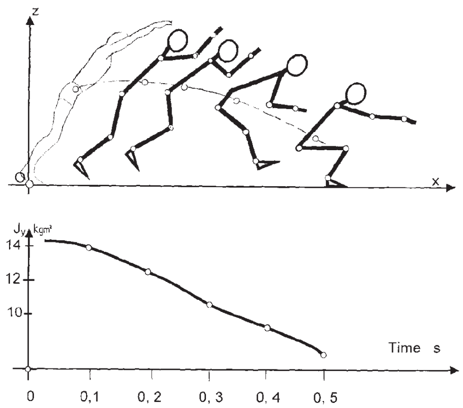

Fig. 1. Standing broad jump as a biomechanical planar task, separate in five different body postures of each 0,1 seconds. Also is shown a diagram that present changes of central moment of inertia J_y.

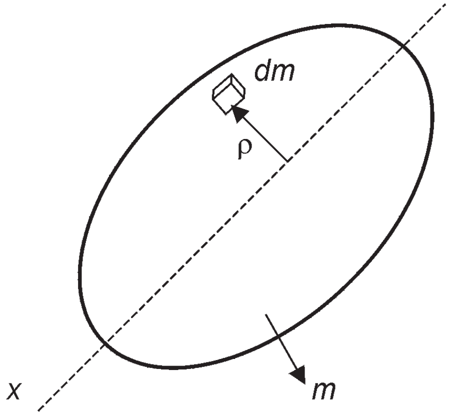

Fig. 2. Genaral case of the body that freely rotate about an axis.

masses of the muscles depend on 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 be involved a group of breast and back's muscles together with shoulder blade. So we have motion of the system with the changeable mass during the motion. As we know internal dynamical moments of inertia are not yet enough investigated.

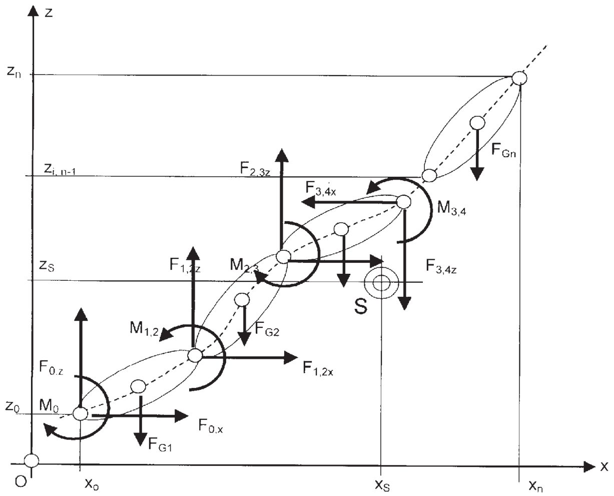

Fig. 3. Planar kinematic chain which represents system of bodies.

Determination of the human mass distribution and body's center of gravity as whole was known a few centuries ago. Borelli (1608–1679) involved such a method. Talking about the methods of mass distribution that were developed, and consequently determination of the centers of gravity, we will start mentioning Fischer and Braun (1889). They involved an approximate method, which is known as »coefficient's method«. They supposed the existence of fixed relations between length of body segment and its mass. From these relations they were able to determine center of gravity, radius of inertia and, of course moment of inertia. Accuracy of this method was doubtful because those coefficients were determined only on three male cadavers.

Much more accurate results in stipulating of the human body mass distribution and respective segmental centers of gravity were determined by Dempster[7] (1961) Division of the body segments is shown in the figure. Also is shown the way of the use of the specially constructed tub; by mean of plunging of body segments into the tubs water that was squeezed out was the measure of the segment volume.

Method for determination of the segmental masses

As the method of the determination of segmental human body masses, also the mass moments of inertia, we used method of Donskij and Zatscijorskij (1979)[3]. This method is extended by suggestions of Muftić (1989)[6] and Muftić, Keros & Božić (1992)[7]. The masses were calculated by mean of the regression formula:

$$m_i = B_0 + B_1 M + B_2 \text{ h, kg}$$

where the B_0, B_1, B_2 are the regression factors calculated by statistical method on 100 examine, M is the total mass of the body, h is the standing height of the individual subject in cm and m_i is analyzed segmental mass.

Modeling of the human body

Our next step consists different kinds of the modeling the body members using geometrical solid bodies. On the first place is the simplest model that we used in the beginning of our process of the modeling. The head and the neck, as well as the hands are modeled as ellipsoids. The forearm, the upper arm, and the two parts of the leg – upper and lower are modeled as cylinders as it is shown in the Figure 4.

The trunk and the foots are modeled as some combinations of parallelepipeds. Expressions for computation of the corresponding central mass moments are:

arm above elbow	$I_{S0} = m_a (r^2/4 + l^2/12)$
hand	$I_{yS0} = 0{,}2\ m_p (b^2 + d^2)$
trunk part	$I_{yS0} = m / 12 (l_1^2 + l_3^2)$
head and neck	$I_{yS0} = 0{,}2\ m_p (b^2 + d^2)$
upper leg	$I_{yS0} = m_n (l^2/12)$
lower leg	$I_{yS0} = m_p (l^2/12)$
foot	$I_{yS0} = m_s/12 (l_1^2 + l_3^2)$.

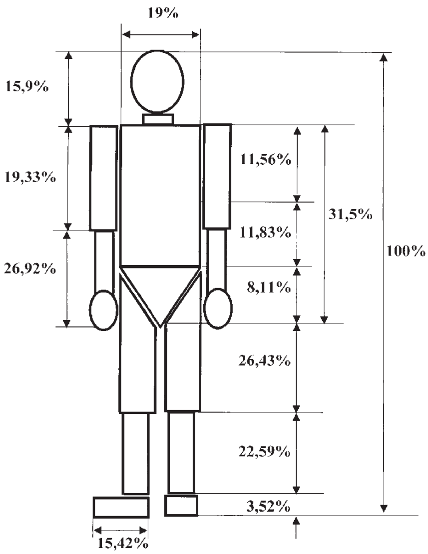

Fig. 4. Simple model of the human body which consists of cylinders, ellipsoids and parallelepipeds.

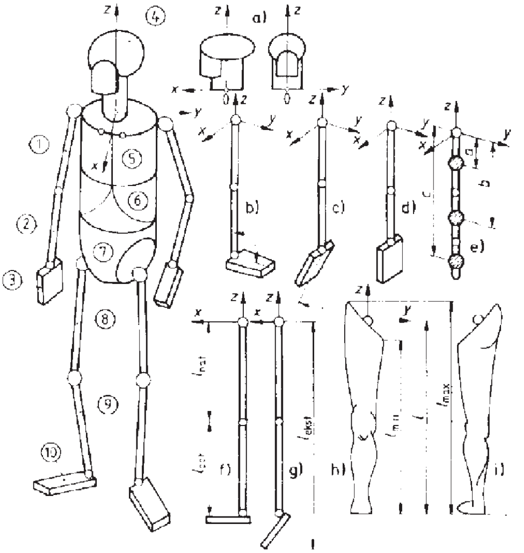

Fig. 5. Presentation of the model selection for computing the segmental mass moments of inertia of a human being. a) one of possible models of head and neck; b), c), d), e) model of hand and its segments; f), i) leg models. In a common model the figure of trunk is shown as cylinders as well.

In the figure are also shown approximated forms, by means of which segments of human body have been modeled, and which are arranged to represent one of possible body positions. The dimensions of geometrical solids depend on their weight and height.

The second kind of the human body model differs a little bit from the previous one. Namely, the segmental parts were modeled as follows:

Head and neck were modeled with ellipsoidal cylinder and with circular cylinder, as it is shown in the Figure 5.

Upper and lower arms as well as legs were modeled with circular cylinders of different sizes. Upper, middle and lower trunk, hands and foots were modeled by means of cylinders, which forms are given also in the figure. Dimensions of supposed body members depend on total weights and standing heights of any individual. Because of that, it is possible to divide into two groups, primary and secondary group. Primary group of dimensions depends only on the subject height that is in accordance with eight canon of head length. Secondary group of dimen-

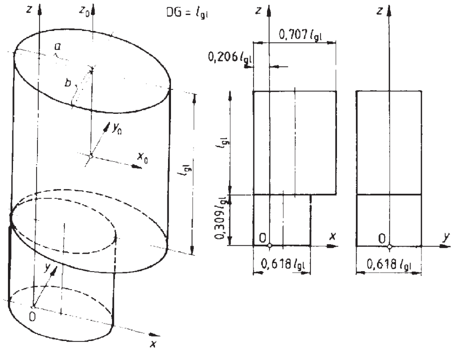

Fig. 6. Simplified model of the head and neck. The origin of the coordinate system is in tenth rib midspine and second cervicale passing the x axis throught supersternale.

sions depend on primary dimensions than about on segmental masses an about of the mean density of the each segment. In our investigations we supposed that mean density of the body is about 1.1 kg/dm^3. But, during the modeling of the parts we have in mind that the mean density of the head and limbs can be supposed as the value of 1.25 kg/dm^3 Because of simplicity we supposed for the head and neck model that is presented in the Figure 6.

Results

By means of Croatian anthropometrical values of population given by Rudan[5], giving them segmental masses distribution, we have calculated the set of the central moments of inertia for trunk, hands, legs

TABLE 1
STATICAL AND DYNAMICAL ANTHROPOMEASURES OF EXAMINED MALES ADOPTED AFTER VALUES OBTAINED BY RUDAN[5]

Measure	5%	25%	50%	70%	95%
Standing height in mm	1592	1620	1648	1724	1801
Upper arm length	288	303	316	326	341
Lower arm length	241	260	270	278	298
Length of the hand	179	180	181	180	182
Arm length *l*	708	743	757	784	821
Center of gravity					
a – upper arm	129,5	136,3	142,1	146,6	153,4
b – lower arm	391	414	431,4	448,8	468,4
c – hand	595	629,5	652,8	670,5	708
L – length of the arm with closed hand	822	653	674	689	720
Mass in kg					
Upper arm	1,53	1,76	1,96	2,17	2,57
Lower arm	0,913	1,05	1,15	1,29	1,53
Hand	0,35	0,398	0,439	0,492	0,538
Arm	2,793	3,208	3,529	3,957	4,687
Leg length in mm	895	911	927	970	1013
Upper leg	448	455	483	485	506
Lower leg with the foot	398	405	412	431	450
Center of gravity					
Upper leg	203	207	211	221	230
Lower leg	161	164	167	175	182
Mass in kg					
Upper leg	7,810	9,050	10,151	11,451	13,751
Lower leg	2,128	2,358	2,668	2,938	3,680
Foot	0,806	0,850	0,921	1,091	1,201
Trunk length in mm	525	535	543	589	594
Trunk mass in kg	24,6	28,2	31,07	34,85	41,28
Total body mass in kg	56,5	64,9	71,5	80,2	95

for axes y, and moment of inertia for head and neck respectively to the x, y, z axes. Results are given in Tables 1–6, where they are separated respectively to the percentile groups for 5, 25, 50, 70 and 95 %. Results are also divided for males and females.

TABLE 2
STATICAL AND DYNAMICAL ANTHROPOMEASURES OF EXAMINED FEMALES ADOPTED AFTER VALUES OBTAINED BY RUDAN[5]

Measure	5 %	25 %	50 %	70 %	95 %
Standing height in mm	1468	1531	1572	1617	1648
Upper arm length	283	280	290	298	315
Lower arm length	222	232	242	252	267
Length of the hand	155	164	166	180	197
Arm length *l*	640	676	698	730	775
Center of gravity					
a – upper arm	118	125	130	134	142
b – lower arm	356	379	393	406	429
c – hand	542	572	593	619	653
L – length of the arm with closed hand	562	594	613	641	681
Mass in kg					
Upper arm	1,40	1,54	1,68	1,90	2,26
Lower arm	0,84	0,92	1,00	1,13	1,35
Hand	0,32	0,35	0,38	0,43	0,51
Arm	2,56	2,81	3,06	3,40	4,12
Leg length in mm	826	861	884	909	947
Upper leg	413	431	442	455	478
Lower leg with the foot	367	382	393	404	421
Center of gravity					
Upper leg	188	196	201	207	217
Lower leg	149	155	159	164	170
Mass in kg	6,951	7,891	8,541	9,851	11,651
Upper leg	1,848	2,010	2,284	2,628	3,032
Lower leg with the foot	0,671	0,711	0,751	0,911	1,011
Trunk length in mm	484	505	519	534	544
Trunk mass in kg	22,6	24,8	27,03	30,05	36,30
Total body mass in kg	52	57	62	70,2	83,5

TABLE 3
CENTRAL DYNAMICAL MOMENTS OF INERTIA OF THE TRUNK RESPECTIVE TO THE Y-AX IN kgm^2 $(ML^2/3)$

	5 %	25 %	50 %	70 %	95 %
Males	0,565	0,673	0,763	0,940	1,210
Females	0,441	0,527	0,607	0,725	0,895

TABLE 4
DYNAMICAL MOMENTS OF INERTIA OF EXTENDED ARM RESPECTIVE TO THE Y AX IN SHOULDER HEAD FOR 3 DIFFERENT LENGTHS ACCORDING TO THE TABLES 1 AND 2 (IN KGM^2)

$J_y = (ml^2/3)$					
Males	0,565	0,673	0,763	0,940	1,210
Females	0,441	0,527	0,607	0,725	0,895
$J_y = (mc^2/3)$					
Males	0,322	0,423	0,502	0,592	0,778
Females	0,250	0,307	0,359	0,450	0,588
$J_y =(mL^2/3)$					
Males	0,360	0,458	0,544	0,626	0,809
Females	0,262	0,330	0,383	0,475	0,637

TABLE 5
DYNAMICAL MOMENTS OF INERTIA OF THE UPPER LEG, LOWER LEG AND WHOLE LEG (IN KGM^2)

$J_y = m_{nat}\ l^2_{nat}/12$					
Males	0,130	0,156	0,181	0,226	0,232
Females	0,099	0,119	0,139	0,170	0,222
$J_y = m_{pot}\ l^2_{pot}\ /12$					
Males	0,028	0,032	0,038	0,045	0,062
Females	0,020	0,024	0,029	0,360	0,045
$J_{y\ leg\ =} m_{leg}\ l^2\ /3$					
Males	1,916	2,188	2,527	3,139	3,974
Females	1,432	1,682	1,956	2,388	3,025
$J_{y,ext} = ml^2_{ext}\ /3$					
Makes	2,042	2,311	2,665	3,324	4,330
Females	1,512	1,774	2,059	2,520	3,188

TABLE 6
DYNAMICAL MOMETS OF HEAD AND NECK RESPECITIVE TO THE AXES X, Y AND Z (IN KGM^2)

J_x					
Males	0,104	0,114	0,128	0,153	0,193
Females	0,069	0,086	0,098	0,112	0,138
J_y					
Males	0,108	0,118	0,129	0,159	0,200
Females	0,072	0,086	0,102	0,117	0,143
J_z					
Males	0,012	0,014	0,015	0,018	0,023
Females	0,008	0,010	0,012	0,013	0,o16

Conclusions

Using developed method, now we are able to predict separated wire model of the adults males and females, knowing its standing height and body mass. This wire models are the basis for multi-body dynamical models, in biomechanical analysis of the human motion, where is necessary also to define muscle attachment points, and develop also internal moments of inertia of the body parts.

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SAŽETA FORMULACIJA ANTROPODINAMIČKIH MJERA U FIZIOLOŠKOJ ANTROPOLOGIJI

SAŽETAK

U ovom je radu opisana jedna interdisciplinarna kombinacija nekoliko stanja metoda iz biomehanike, dinamike višečlanih sustava i modeliranja ljudskog tijela. Opisivanje je ljudskog lika u gibanju veoma važan dio biomehaničkih analiza. U ovakvih suvremenih metoda je potrebno koristiti dinamički moment raspodjela masa, kao temeljni dio dinamičke antropometrije u kojima se opisuju gibanja čovjeka. Cilj je ovog rada bio korištenje i prilagodba postojećih tehnika, kao i istraživanje toga što još treba analizirati kako bi se mogli zajednički koristiti. Prvo su date opće definicije i opisi pojma dinamičkog momenta tromosti i njihova prilagodba antropometrijskim vrijednostima u našoj populaciji. Drugo, dat je i pregled nekih jednostavnih modela pomoću kojih se mogu odrediti odgovarajući momenti tromosti segmenata čovjekova tijela za vrijeme njegova gibanja. Rezultati su dati u obliku odgovarajućih jednadžbi i tabelarno, kojima je prikazana funkcionalna veza između izabranih segmenata ljudskog tijela s odgovarajućim statističkim raspodjelama antropodinamičkih vrijednosti u koracima od 5%, 25%, 50%, 79% i 95%, kako za muške tako i za ženske subjekte.