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CAD MODELLING OF FEMALE HUMAN BODY FOR STUDY OF MASS-INERTIAL PARAMETERS

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Abstract: *The knowledge of mass-inertial characteristics of the human body is needed in order to properly design wearable or rehabilitation robots and devices. The aim of the current work is: 1) to propose 16-segmental biomechanical model of the female body and to generate that model within a SolidWorks medium 2) to verify the model via comparing the results for the mass-inertial parameters of the body obtained within the model with the analytical results from our previous investigation; 3) to obtain new results for the mass-inertial characteristics of the whole female human body of the average Bulgarian female on the basis of the model in various body positions. In the current article, we accomplished the above program and report data for the mass-inertial parameters of the female body in two basic positions - the standing position and the sitting position. The comparison performed between our model results and data reported in literature gives us confidence that this model could be reliably used to calculate these characteristics at any another posture of the body of interest when studying these parameters related to problems appearing in the everyday live, work, leisure, sport, criminology, rehabilitation, in space exploration with the participation of female astronauts, etc.*

1 INTRODUCTION

When one scientifically studies the motion of the human body as total, or of its parts, one usually does that on the specific example of the human body. Unfortunately, most of the data about mass-inertial parameters available in literature concerns males. In additions, in the rear cases when such data are reported for women, almost all of them is about the different segments, not for the body as a whole. In the current article we will present a 3D model of the female body and with the help of it computer realization within the SolidWorks media will provide data for the mass-inertial parameters of the female body in its two basic positions.

When one aims to study the behavior of the human body, obviously the knowledge of the corresponding geometric and mass-inertial characteristics (volume, mass, center of mass, moments of inertia) both for the whole body, as well as of body segments, is needed. As regard the measurements of females, initially in [1] using stereophotogrammetry one has developed regression equations on the base of a sample of 46 adult women. Then in [2], based on the elliptical zone method, one evaluated 15 females and classified them into endo-, meso- and ecto-morphs. In [3], the mass-inertial parameters of 15 female athletes using gamma-scanner method were obtained. A method for more accurate estimation of mass and center of mass location of the body segments of the general population of older adults (29 men, 50 women) is proposed in [4]. Finally, in [5] regression equations for estimating length, mass and moments of inertia of the segments of the human body have been derived on the basis of measurements of 25 young Caucasian females.

Surely, the generation of 3D model of the human body in a CAD media needs knowledge of anthropometry and biomechanics. One should, effectively find the solution to specific problems related to: a) correct body decomposition; b) the selection of necessary anthropometric landmarks; c) the choice of the geometrical bodies with which the corresponding segments of the body shall be modeled; d) model generation within a proper CAD system (e.g. SolidWorks); e) The verification of the so generated model via comparison with analytical results in order to show that computer generated model provides reliable data quantities.

Let us stress that understanding the mass-inertial parameters of the body is of importance in orthotics and prosthetics design, ergonomics, sports, proper design of wheelchairs, rehabilitation devices, etc. We hope that our model will be helpful in these areas.

In the current article, we suggest a 3D model of the human body of the Bulgarian woman able to predict the inertial properties of the human body in any fixed body position. The model could be used to develop a design guide for some of the problems mentioned above. After generating the model within the CAD system SolidWorks, we obtain the mass-inertial characteristics of an average Bulgarian female. In addition, wherever possible we will present a comparison of our results with data available in literature for other Caucasian women.

2 MODEL AND METHOD

As explained in [6], the model consists of 16 segments representing: head + neck, upper, middle and lower part of torso, thigh, shank, foot, upper arm, lower arm and hand, assumed to be relatively simple geometrical bodies. We accept full body symmetry with respect to the sagittal plane. The geometrical data needed is from a detailed representative anthropological investigation of the Bulgarian population [7]. A total of 2854 females at the age 31-40 years were measured. We take the average values found in the above investigation and design a model, which represents the so defined “average” Bulgarian female.

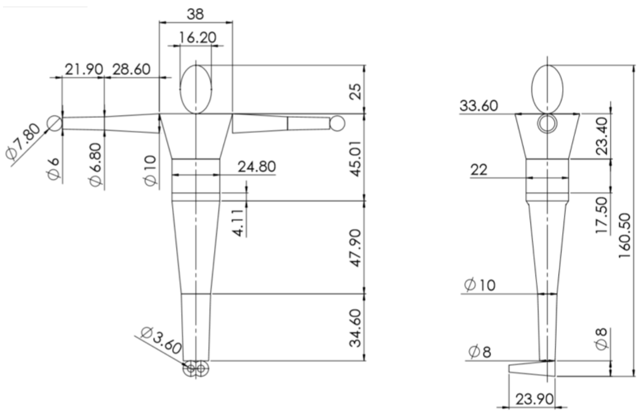

Figure 1: 16-segemental model of the female human body and the corresponding dimensions [cm].

The basic features of the model are visualized in Fig. 1. In [6] one provides the appropriate body decomposition, the choice of necessary anthropometric points, the description of the geometrical bodies used to model the different segments of the body, the corresponding anthropometric data required for determination of their characteristics, as well as mathematical expressions needed for the analytical evaluation of the mass-inertial parameters of the different segments of the body. We refer the interested reader for details to [6].

Here we are going to present only some brief comments in order to introduce the very basic facts for the model used in the current study - see Fig. 1. The segments are modeled by means of geometrical bodies: (1) the head + neck are modelled as an ellipsoid; (2) the torso is decomposed in three parts; (3) the upper part of the torso is approximated by means of a right reverted elliptical cone; (4) we specify both middle and lower torso according to [3] modeled as an elliptical cylinder and an elliptical cylinder + reverted elliptical cone, respectively; (5) all segments of both the lower and upper extremities are assumed to be cone frustums and the hand is modeled as a sphere. The decomposition of the body segments is made according to anthropometric points used in [3]. It is described in details in [6], where after determining the geometrical parameters of the segments, the model has been used to determine the mass-inertial parameters of the different segments of the body.

In order to obtain the mass-inertial characteristics of the body in a given position we have performed a realization of the model in CAD system – SolidWorks. We have verified the computer interpretation by comparing the results it delivers for the mass-inertial parameters of the segments of the body with those reported in [6].

The basic positions of the body have been classified long time ago in the literature – see, e.g., [8. 9, 10, 11]. One usually considers eight principal body positions. Unfortunately, the data from the above surveys is only for men while for women they are either missing or are very few and not enough for reasonable statistically verifiable estimations. In the following sections we will try to enrich the literature with data for two of these positions: the so-called standing position– see Fig. 2 and the so-called sitting position– see Fig. 3.

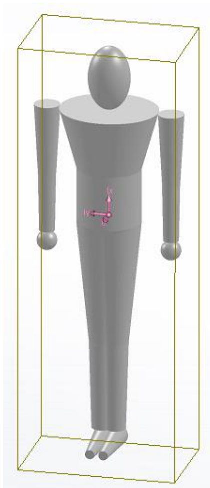

Figure 2: Standing position: Subject stands erect with head oriented in the Frankfort plane and with arms hanging naturally at the sides as when measuring.

3 DETERMINATION OF MASS-INERTIAL CHARACTERISTICS USING SOLIDWORKS MEDIA

To generate the model, 3D CAD Design engineering-oriented software SolidWorks is used. The product is an engineering-oriented CAD/CAM system with capabilities, similar to those of systems of the highest class - CATIA, I-DEAS, Pro/Engineer, UNIGRAPHICS.

We introduce the model elements in SolidWorks medium as an aggregate of features. Each component is an independent 3D object, having different parameters and topology characteristics. We characterize each segment by its dimensions and density. The software calculates the segment volume, mass, surface area, position of the mass center, principal moments of inertia and the inertial tensor. Thus the human body model is accomplished and the mass characteristics with respect to right-handed Cartesian coordinate frame oriented at its center of mass are determined.

The so computer-generated model is verified by comparing its results with those reported in [6] for the different segments of the body. The program reproduces segment-by-segment data about volume, mass, center of mass and moments of inertia. That gives us confidence that this model could be used to calculate these characteristics at different body positions of the body.

As stated above, we consider the “standing position” and “sitting position”. For this positions, a system of axes with an origin at the center of mass is defined. The axes coincide with the approximate body axes: the frontal (y), the sagittal (z), and the longitudinal (x) ones. Following the definition of [10] in the “standing position” the individual stands erect with head oriented in the so-called Frankfort plane and with arms hanging naturally at the sides - see Fig. 2.

The data for the mass-inertial characteristics of the female body in standing position is presented in Table 1. Of course, in order to make a reasonable comparison with the mass-inertial data reported in [1], both the coordinate system, as well as the corresponding units, have been converted to the ones used in present study.

Table 1 provides also data for the average height and mass of person in the corresponding study compared with the investigations of [1] and [12].

Characteristic	**Ref [1]**			**Ref. [12]**	**Our data**
	Min	Man	Mean	-	
I_{XX} [kg.cm^2×10^3]	5.8	24.0	11.6	-	6.7
I_{YY} [kg.cm^2×10^3]	49.1	135.0	85.0		78.3
I_{ZZ} [kg.cm^2×10^3]	53.0	135.0	91.9	-	81.9
Stature [cm]	161.20			162.60	160.51
Mass [kg]	63.90			64.64	60.65
Center of mass [cm]	-			-	67.3

Table 1: Standing position.

Table 1 contain data for the center of mass in the corresponding posture of the body measured from the anthropometric point vertex of the head (the “x” coordinate) and from the sagittal plane through the middle of the body when in standing position.

The inspection shows a reasonably good agreement between our results and those previously reported in the literature.

Next, we present data for the sitting position – see Fig. 3.

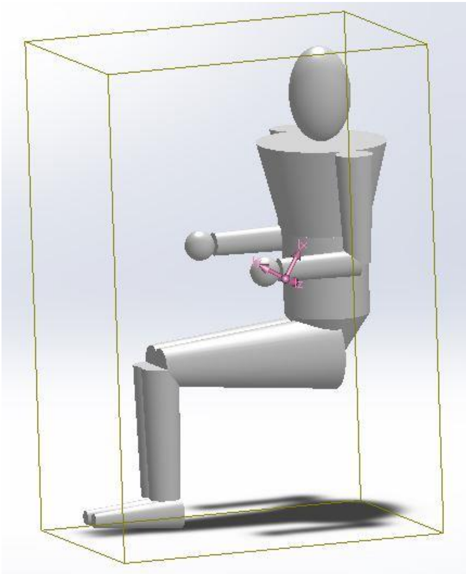

Figure 3: Sitting position: Thighs and forearms parallel to the Z-axis; upper arms, shanks and spine parallel to the X-axis; soles parallel to X-Y plane; wrist axes parallel to X-axis; head in Frankfort plane.

The axes of the basic coordinate system are again chosen to coincide with the approximate body axes: the frontal (y), the sagittal (z), and the longitudinal (x) ones. One obtains that the mass center is at a distance C_X = 60.16 cm from the *vertex* of the head and with x and y coordinates C_Y = 0, due to the preserved right-left symmetry, and C_Z = 11.23 cm. The principal moments of inertia in the coordinated system centered at the mass center are I_{XX}=12.8 [kg.cm^2×10^3], I_{YY}=56.7 [kg.cm^2×10^3] and I_{ZZ}=59.2 [kg.cm^2×10^3]. Unfortunately, for this body position we are not aware of other data for females with which we can perform a comparison.

6 CONCLUSION

In the current study we have presented 3D biomechanical model of the human body of women on the basis of the original anthropometrical data [7]. The specific geometrical realization reflects the “average” Bulgarian woman.

Unfortunately, the overwhelming amount of data available in literature, due to a variety of different reason, concerns males. Next, even when such measurements for females have been performed, almost all available data is about the different segments, not for the body as a whole. Therefore, the proposed approach aims to fill in partially this gap.

The model is generated in SolidWorks environment. Using it, data for the mass-inertial characteristics of the body in the so-called standing and sitting position have been obtained and compared with those reported in the literature, where such data are available. The comparison demonstrates good agreement, which gives us confidence that this model can be used to reliably calculate the mass inertial characteristics at any specific posture of the body. Let us note that the model is suitable for the performance of static, kinematic and dynamic analysis. A modification of the model so that it can represent a specific individual is easily achievable by using the individual anthropometric dimensions for that person.

The model can be used in rehabilitation robotics, computer simulations, medicine, sports and in other issues such as simulation of the human behavior in space, sports, ergonomics, criminology and other areas.

In order to reduce the differences between our results obtained and those available in literature, we plan to improve the modelling of the segments by using geometrical bodies closer to the real shape of the segments of the human body. For that aim, one needs to collect data for additional anthropometric parameters. This is currently in progress. Of course, for the new set of geometric bodies one will need again to derive analytical expressions for their mass-inertial parameters and to compare with those obtained through the corresponding realization of the modified model within a suitable CAD/CAM system.

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