REFINING OF THE HANAVAN HUMAN BODY MODEL FOR KINEMATICS INVESTIGATION OF ATHLETES MOTION

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INTRODUCTION

During the last few years the researchers of the Department of Technical Mechanics of T.U. of Budapest developed a software-package for analysing the motion of athletes

Requirements against the analysing software package:

- suitability for analysing simple video records
- easy of handling by minimising the number of necessary key points
- possibility of correcting errors caused by input data
- suitability for determining the center of mass and moments of inertia of the body segments
- ability to describe the effect of sports instruments
- suitability of motion simulation

MECHANICAL MODEL OF THE HUMAN BODY

This paper presents the applied model with special regard to the geometric modelling of the torso. The model is a refined Hanavan model [4] representing the human body by 16 simple geometric solids determined by the spatial co-ordinates of 20 key points.

DETERMINATION OF THE MASS CENTER OF THE BODY SEGMENTS

$$\bar{r}_{si} = \bar{r}_i + \xi_i\left(\bar{r}_{i+1} - \bar{r}_i\right) \qquad (1)$$

the values of ξ_i are in Table 1.[1, 2, 3, 4]

element	value of ξ_i	remark
hand	0.94	from the fingertip
forearm	0.57	from the wrist
upper arm	0.564	from the elbow
foot	0.571	from the toe
calf	0.567	from the ankle
thigh	0.567	from the knee

Table 1.

DETERMINATION OF THE MASS CENTER FOR THE WHOLE BODY

$$\bar{r}_s = \frac{\sum_{i=1}^{16} m_i \bar{r}_{si}}{\sum_{i=1}^{16} m_i} \qquad (2)$$

where $m_i = c_i m$ (3)

m = the mass of the whole body

The values of c_i are in table 2. [1, 2 3.41

	rotund	muscular	thin	median	density kg/m3
hand	0.004	0.005	0.006	0.005	1490
forearm	0.015	0.017	0.016	0.016	1340

upper arm	0.033	0.034	0.030	0.035	1010
foot	0.011	0.013	0.015	0.013	1670
calf	0.045	0.044	0.048	0.047	1200
thigh	0.148	0.129	0.129	0.137	1170
head + neck	0.079	0.079	0.079	0.079	1180
thorax (chest)	0.2	0.208	0.208	0.2	950
abdomen (stomach)	0.089	0.099	0.095	0.085	995
pelvis (hip)	0.12	0.13	0.13	0.13	1040

Values of c_i and the density of the segments
Table 2.

MASS MOMENTS OF INERTIA
Model to determine the moments of inertia can be seen in Figure 2.
The elements of the model are truncated cones for the limbs and elliptic cylinders for the torso and a sphere for the head.

EQUATIONS FOR THE TRUNCATED CONE ELEMENTS MODELLING THE SEGMENTS 1-12 (see Figure 3.):
The elements of the matrix of mass moments of inertia in the local **co-ordinate** system:

$$I_{xx} = m\left(\frac{AA.V}{h} + BBh^2\right) \qquad (4)$$

$$I_{yy} = I_{xx} \qquad (5)$$

$$I_{zz} = 2.AA.m.\frac{V}{h} \qquad (6)$$

$$\textit{here} \qquad AA = \frac{9}{20\pi}\frac{1+p+p^2+p^3+p^4}{\sigma^2}$$

$$BB = \frac{3}{80}\frac{1+4\mu+10\mu^2+4\mu^3+\mu^4}{\sigma^2}$$

$$\mu = \frac{R}{r}\ , \quad \sigma = 1+\mu+\mu^2$$

R and **r** can be **determined** from the following equations:

$$V = \frac{m}{\rho} = \frac{h\pi}{3}\left(R^2 Rr + r^2\right) \qquad (7)$$

$$x = \frac{h}{4}\frac{R^2+2Rr+3r^2}{R^2+Rr+r^2} \qquad (8)$$

ρ – density

EQUATIONS FOR THE TORSO
The torso is determined by three segments (upper torso - chest; middle torso - stomach; lower torso - hip), modelling by elliptic cylinders which may rotate in space relative to each others. (see figure 4.)

EQUATIONS FOR THE UPPER ELEMENT

$$\bar{r}_{21} = \frac{1}{2}\left(\bar{r}_4 + \bar{r}_5\right) \tag{9}$$

$$L_{14} = 2\lambda_{14}\left|\left(\bar{r}_{18} - \bar{r}_{21}\right)\right| \tag{10}$$

$$R_{14} = \frac{1}{2}\left|\left(\bar{r}_5 - \bar{r}_4\right)\right| \tag{11}$$

$$r_{14} = \frac{m_{14}}{\rho_{14} R_{14} L_{14} \pi} \tag{12}$$

$$\bar{r}_{23} = \bar{r}_{21} - \frac{L_{14}}{2}\frac{\left(1+\lambda_{14}\right)}{\lambda_{14}}\bar{e}_z^{(14)} \tag{13}$$

$$\bar{e}_z^{(14)} = \frac{\bar{r}_{21} - \bar{r}_{18}}{\left|\left(\bar{r}_{21} - \bar{r}_{18}\right)\right|} \tag{14}$$

$$\bar{e}_x^{(14)} = \frac{\left(\bar{r}_5 - \bar{r}_4\right) \times \bar{e}_z^{(14)}}{\left|\left(\bar{r}_5 - \bar{r}_4\right) \times \bar{e}_z^{(14)}\right|} \tag{15}$$

$$\bar{e}_y^{(14)} = \bar{e}_z^{(14)} \times \bar{e}_x^{(14)} \tag{16}$$

EQUATIONS FOR THE LOWER ELEMENT

$$\bar{r}_{22} = \frac{1}{2}\left(\bar{r}_{12} + \bar{r}_{13}\right) \tag{17}$$

$$L_{16} = 2\left|\left(\bar{r}_{20} - \bar{r}_{22}\right)\right|\lambda_{16} \tag{18}$$

$$R_{16} = \frac{1}{2}\left|\left(\bar{r}_{13} - \bar{r}_{12}\right)\right|\lambda_q \tag{19}$$

$$r_{16} = \frac{m_{16}}{\rho_{16} R_{16} L_{16} \pi} \tag{20}$$

$$\bar{r}_{24} = \bar{r}_{22} + \frac{L_{16}}{2}\frac{1+\lambda_{16}}{\lambda_{16}}\bar{e}_z^{(16)} \tag{21}$$

$$\bar{e}_z^{(16)} = \frac{\left(\bar{r}_{20} - \bar{r}_{22}\right)}{\left|\left(\bar{r}_{20} - \bar{r}_{22}\right)\right|} \tag{22}$$

$$\bar{e}_x^{(16)} \quad \frac{\left(\bar{r}_{13} \quad \bar{r}_{12}\right) \quad \bar{e}_z^{(16)}}{\left|\left(\bar{r}_{13} \quad \bar{r}_{12}\right)\right| \quad \bar{e}_z^{16}} \tag{23}$$

$$\bar{e}_y^{(16)} \quad \bar{e}_z^{(16)} \quad \bar{e}_x^{(16)} \tag{24}$$

EQUATIONS FOR THE MIDDLE TORSO

$$L_{15} \quad \left|\left(\bar{r}_{23} - \bar{r}_{24}\right)\right| \tag{25}$$

$$R_{15} = \frac{1}{2}\left(R_{14} + \frac{R_{16}}{l_q}\right) \qquad (26)$$

$$r_{15} = \frac{m_{15}}{r_{15} L_{15} R_{15} P} \qquad (27)$$

$$\bar{e}_z^{(15)} \quad \frac{(\bar{r}_{20} - \bar{r}_{22})}{\left|(\bar{r}_{20} - \bar{r}_{22})\right|} \qquad (28)$$

$$\bar{n}_k \quad \bar{e}_y^{(14)} \quad \bar{e}_y^{(16)} \qquad (29)$$

$$\bar{e}_x^{(15)} \quad \frac{\bar{n}_k \quad \bar{e}_z^{(15)}}{\left|(\bar{n}_k \quad \bar{e}_z^{(15)})\right|} \qquad (30)$$

$$\bar{e}_y^{(15)} \quad \bar{e}_z^{(15)} \quad \bar{e}_x^{(15)} \qquad (31)$$

For the control of the right position:

$$\bar{r}_{19} \quad \frac{1}{2}(\bar{r}_{23} \quad \bar{r}_{24}) \qquad (32$$

l_{14}, l_{16} *and* l_q are parameters determining the dimenzions of the elliptic cylinders.

THE ELEMENTS OF THE MASS MOMENTS OF INERTIA IN THE LOCAL COORDINATE SYSTEM FOR EACH ELEMENT:

$$I_x^{(i)} \quad m_i \frac{3R_i^2 \quad L_i^2}{12} \qquad (33)$$

$$I_y^{(i)} \quad m_i \frac{3r_i^2 \quad L_i^2}{12} \qquad (34)$$

$$I_z^{(i)} \quad m_i \frac{R_i^2 \quad r_i^2}{4} \qquad (35)$$

CONCLUSIONS

The reviewed mechanical model of the human body is suitable for calculating the mass center and the elements of the mass moments of inertia with negligible error, and the developed software package, based on (1)-(35) equations, is reeommanded for analyzing the motion of athletes.

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