# VISUALIZATION OF MOVEMENT IN GYMNASTICS EXERCISES

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**ABSTRACT**

*Visualization of the movement is crucial both for research and pedagogical activities. The aim of this study was to introduce some methodology for the visualization of the movement on the basis of the data obtained from conducting numerical experiments when studying various movements and exercises. The main task was to design a program module for the visualization of spatial movements. The visualization of the results from the conducted simulations allows for having an idea of the studied movement in the course of solving the equations of motion. The program module for the visualization of an athlete's movement is working in the MATLAB Computing Environment. We have constructed an anthropomorphic structure (model) which resembles the shape of a human body. The model possesses a high degree of mobility which makes it suitable for applying various movements and actions. A set of artistic gymnastics exercises was provided as an example. The visualization of the current results from the simulated movement contributes to the detailed analysis and facilitates the interpretation of the obtained results. The model can also be applied to research activities for movements in other sports.*

***Keywords***: *visualization, simulations, model, gymnastics*

## INTRODUCTION

Presenting the obtained kinematic data properly is crucial for achieving greater efficiency when studying a movement. The visualization of sports movements is essential for clarifying some details of sports technique. Prior to designing a method for a visual presentation of an athlete's movements, some details should be specified. Depending on the specificity of the object to be presented and the motor activity to be visualized, we determine the degree of mobility of the visualizing model. The number of segments and the way they connect (joint connections) are specified. There are visual demonstrations of motor activities for clarification of issues related to sports technique in a number of scientific studies. Bauer (1985) designed a manually managed model of a gymnast to demonstrate some basic biomechanical principles in teaching a horizontal bar and showed the effect of changing some of the parameters. The model consists of three segments; its height is 0.75 m; it is with geometrically proportional segments like a 1.75 m tall gymnast. Yeadon et al. (1990) applied a sequence of graphic images upon simulation of rotation movements in the flight phase. In simulating sports exercises, Casolo and Zappa (1992) demonstrated a graphical spatial representation of movement. The researched exercises were visualized through images imitating the human body. To clarify some specific rotations in the shoulder area, the so-called Codman's Paradox, Cheng (2006) developed a 3D model of an arm (he used 3D graphic functions of Matlab). Kiuchukov and Kulishev (2007) studied some possibilities for 3D visualization of gymnastics movements and their benefits for the analysis of technique. In their survey, Kiuchukov and Yanev (2014) presented models for the visualization of gymnastics exercises. The models can be applied in gymnasts' training. Dallas and Theodorou (2020) investigate the influence of visual regulation on some kinematic characteristics of the vault in artistic gymnastics.

One of the key stages in modeling and visualization of 3D human movements is the selection of the appropriate parameters determining the orientation of the body/segments in space. Various parameters have been applied depending on the specifics of the studied movement (Shoemake, 1985; Stirling et al., 2010; Engin & Peindl, 1987; Peindl & Engin, 1987; Raikova, 1992; Baker, 2011; Cheng, 2000, 2004).

Nowadays, kinematic data about certain exercises can be used to visualize the movements by applying some of the numerous software products (usually commercial ones). This process, however, may be hard to apply and takes time.

The aim of this study was to introduce a methodology for the visualization of the movement. The data obtained from the numerical experiments were used. The visualization of the current results is carried out during the numerical solution of the equations of motion. This will allow for an immediate visual idea of the studied movement and facilitate the analysis of an athlete's motor manifestation.

## METHODOLOGY

The first thing was to determine the structural peculiarities of the anthropomorphic construction (model), which would be used to visualize an athlete's movements.

### *Structure of the model*

The presented model consists of 16 rigid segments, which include: three segments for each upper limb (upper arm, forearm, hand); three segments for each lower limb (thigh, shank, foot); one segment for the head and neck. To achieve greater mobility, the torso was divided into three parts. The relative motions among the sixteen segments are helped by 15 joints allowing a high degree of agility – 32 inner degrees of freedom. The outer degrees of freedom are 6 (3 rotational and 3 translational). The number of rotations of each joint is shown in Figure 1.

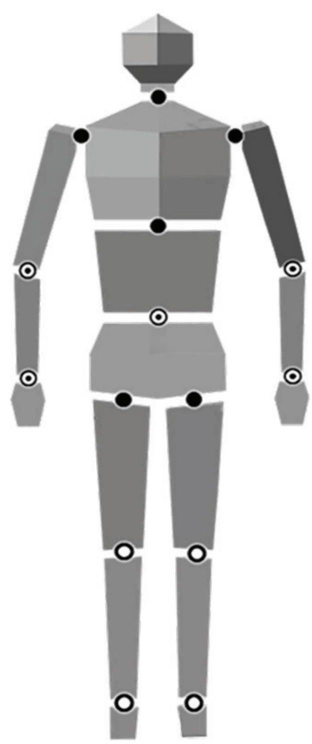

**Figure 1.** *Body segments and joints. The number of the degrees of freedom in the joints is indicated with: ● - 3 degrees of freedom; ◉ - 2 degrees of freedom; ○ - 1 degree of freedom*

The characteristic anatomical movements accessible for imitation are: at the shoulder and hip joints – flexion/extension, abduction/adduction, internal/external longitudinal rotation; at the elbow joints – flexion/extension, pronation/supination; at the wrist joints – flexion/extension and abduction/adduction; at the ankle and knee joints – flexion/extension. The movements between the upper and middle part of the torso are: flexion/extension, left/right lateral flexion, and longitudinal rotation. Between the middle and lower part of the torso – flexion/extension and left/right lateral flexion. The head has three rotation degrees of freedom which allow for flexion/extension, lateral bending to the left/right, and longitudinal rotation.

In order to determine the anthropometric characteristics of the body, the method described by Zatsiorsky et al. (1981) was applied.

***Determining the orientation of the different body segments. Transformation matrixes***

Usually, one of the segments plays a specific role in presenting the dependencies between the movements. This segment is called basic, and in this model, it is the middle part of the torso (B1). In the presented model, the parameters for determining the orientation of the segments are the modified angles of Euler, known as rotations x-y-z or angles of Bryan. These angles serve to determine the orientation both of the basic and the other body segments.

The definition of the angles is related to determining the relevant coordinate system (S). We introduce a stationary coordinate system (So) OXYZ, according to which we calculate the global movement. Two coordinate systems are attached to each segment. One of them ($S_{Ci}$) $C_i X_i Y_i Z_i$ is with the origin in the center of gravity of the particular segment $C_i$ (i = 1,...,16). The origin of the other coordinate system ($S_{Oi}$) $O_i x_i y_i z_i$ is situated at the joint $O_i$ (i = 2,...,16) of the proximal end of the particular segment. These two local coordinate systems are fixed to their relevant segment ($B_i$) and rotate together with it (Figure 2). The beginning of the non-rotating coordinate system $CX_CY_CZ_C$ is connected to the body's center of gravity.

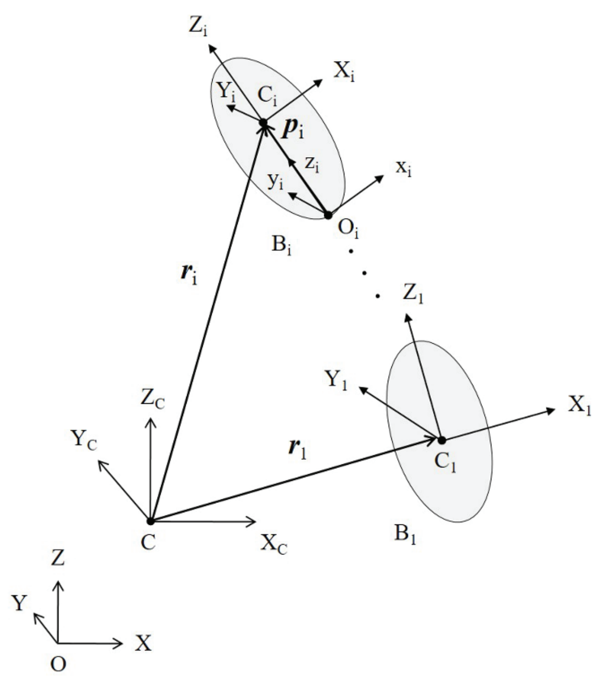


**Figure 2.** *Coordinate system: OXYZ – stationary in space; $CX_CY_CZ_C$ - non-rotating; $C_iX_iY_iZ_i$ and $O_ix_iy_iz_i$ - fixed at the different segments ($B_i$)*

The applied system of modified angles of Euler (1-2-3) corresponds to the following consecutive rotations:

- rotation of angle $\Phi$ around the axis OX, matrix $\mathbf{G}_{x,\phi}$,
- rotation of angle $\theta$ around the axis OY', matrix $\mathbf{G}_{y,\theta}$,
- rotation of angle $\psi$ around the axis OZ'', matrix $\mathbf{G}_{z,\psi}$.

The resultant matrix of this transition between the coordinate system is of the kind: $\mathbf{G}_{\phi,\theta,\psi} = \mathbf{G}_{x,\phi}\mathbf{G}_{y,\theta}\mathbf{G}_{z,\psi} =$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\phi & -s\phi \\ 0 & s\phi & c\phi \end{bmatrix} . \begin{bmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\theta \end{bmatrix} . \begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} =$$

(1)

$$= \begin{bmatrix} c\theta c\psi & -c\theta s\psi & s\theta \\ c\phi s\psi + s\phi s\theta c\psi & -s\phi s\theta s\psi + c\phi c\psi & -s\phi c\theta \\ s\phi s\psi - c\phi s\theta c\psi & c\phi s\theta s\psi + s\phi c\psi & c\phi c\theta \end{bmatrix},$$

where s ≡ sin, c ≡ cos.

We apply this kind of matrix for rotations at the joints with three degrees of freedom. The rotations of the basic segment relative to the non-rotating coordinate system are also determined with a transition matrix of the kind shown above.

For joints with two degrees of freedom of movement (elbow joints), we use a transition matrix of the kind:

(2) $$\mathbf{G}_{\theta,\psi} = \mathbf{G}_{y,\theta}\mathbf{G}_{z,\psi} = \begin{bmatrix} c\theta c\psi & -c\theta s\psi & s\theta \\ s\psi & c\psi & 0 \\ - \ \theta c\psi & \theta \ \psi & \theta \end{bmatrix}.$$

There are two degrees of freedom at the joints of the wrists and in the movements between the middle and lower part of the torso. The relevant matrix in this transition is of the kind:

(3) $$\mathbf{G}_{\phi,\theta} = \mathbf{G}_{x,\phi}\,\mathbf{G}_{y,\theta} = \begin{bmatrix} c\theta & 0 & s\theta \\ s\phi s\theta & c\phi & -s\phi c\theta \\ -c\phi s\theta & s\phi & c\phi c\theta \end{bmatrix}.$$

One rotation is performed at the knee and ankle joints with transition matrix:

(4) $$\mathbf{G}_{x,\phi} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\phi & -s\phi \\ 0 & s\phi & c\phi \end{bmatrix}.$$

All of the matrixes shown above describe the transition from the coordinate system i to the coordinate system i-1. In order to indicate the direction of the transition, we introduce an upper and a lower index. For instance, the matrix $\mathbf{A}_{i}^{i-1}$ is a transition matrix from the coordinate system i to coordinate system i-1. For greater compactness of the expressions, we introduce the transition matrixes in rotation and translation as a homogeneous transformation with matrixes of the kind:

(5) $$\mathbf{A}_{i}^{i-1} = \mathbf{T}_{i}^{i-1}\mathbf{R}_{i}^{i-1} = \begin{bmatrix} 1 & 0 & 0 & \\ 0 & 1 & 0 & [\boldsymbol{l}_{i}^{i-1}]_{(3\times1)} \\ 0 & 0 & 1 & \\ 0 & 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} & & & 0 \\ & [\mathbf{G}_{i}^{i-1}]_{(3\times3)} & & 0 \\ & & & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \mathbf{G}_{i}^{i-1} & \boldsymbol{l}_{i}^{i-1} \\ \mathbf{0}_{(1\times3)} & 1 \end{bmatrix},$$

Where the matrix $\mathbf{G}$ is with size 3×3 and is of the kind (1), $\boldsymbol{l}_{\mathrm{i}}^{\mathrm{i}-1} = \left[x_{Oi}^{i-1} \quad y_{Oi}^{i-1} \quad z_{Oi}^{i-1}\right]^{\mathrm{T}}$ is a vector with components the coordinates of the origin $O_i$ of the coordinate system $O_i x_i y_i z_i$, projected in the coordinate system $O_{i-1} x_{i-1} y_{i-1} z_{i-1}$, "т" is a sign for transponation. The matrix $\mathbf{0}_{(1 \times 3)} = [0 \quad 0 \quad 0]$ is with size 1×3. For instance, if $\boldsymbol{p}_{\mathrm{i}}^{\mathrm{i}} = [x_{Ci} \quad y_{Ci} \quad z_{Ci} \quad 1]^{\mathrm{T}}$ is a position vector of the center of gravity $C_i$ from segment i, presented in the local coordinate system (i.e., it is situated at the proximal end of the segment and connects the origin of $O_i x_i y_i z_i$ and $C_i$), we can express this vector in the starting coordinate system $CX_CY_CZ_C$ through homogeneous transformations:

$$\boldsymbol{p}_{\mathrm{i}}^{\mathrm{c}} = \mathbf{A}_1^{\mathrm{c}} \mathbf{A}_2^1 \ . \ . \ . \ \mathbf{A}_{\mathrm{i}}^{\mathrm{i}-1} \boldsymbol{p}_{\mathrm{i}}^{\mathrm{i}} \tag{6}$$

Where subscript $\mathbf{A}_1^{\mathrm{c}} \mathbf{A}_2^1 \ . \ . \ . \ \mathbf{A}_{\mathrm{i}}^{\mathrm{i}-1}$ are matrixes of transition between the corresponding coordinate systems of the different bodies. Generally, when we have "n" number of bodies (when numbering the segments consecutively), the transition from the local ($S_n$) to the reference ($S_j$) coordinate system is made with the matrix:

$$\mathbf{A}_{\mathrm{n}}^{\mathrm{j}} = \prod_{\mathrm{i}=\mathrm{j}}^{\mathrm{n}-1} \mathbf{A}_{\mathrm{i}+1}^{\mathrm{i}}$$

The local coordinate systems of all segments are shown in Figure 3.

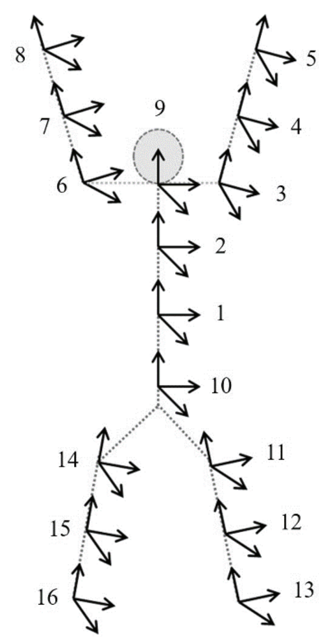


**Figure 3.** *Local coordinate systems*

After the numerical solution of the differential equation, we obtain the values of the three angle coordinates ($\phi_1$, $\theta_1$ and $\psi_1$) of the basic segment for each step in the integration process. These values can be presented as an array of numbers in a table format or a graphic format – curves as functions of time. However, their presentation in this way significantly impedes the perception of the simulated movement. We think that the rational solution is the creation of a program for the visualization of the current results. In this case, the data are redirected to the visualization subprogram after each stage of integration, and we receive an image (frame) showing the orientation and configuration of the body within the current time. In this way, we can obtain a clear vision of the movement during the very process of integration. The graphic images imitate the shape of a human body (Figure 4) and frame by frame, they present the execution of the set motor program. Each depicted body segment is a simple geometric construction, which is easy to build when we know the Cartesian coordinates of the points determining the shape of the particular segment. If we increase the number of points used for the shape, we will achieve a more detailed visualization, but given the aim of the visualization, it is not necessary. At first, the coordinates of the points used for the construction of a particular segment are determined in the local coordinate system of the segment ($O_ix_iy_iz_i$ or $C_1X_1Y_1Z_1$ for the basic segment B1). For the transfer of the coordinates in the global coordinate system (OXYZ), we apply the matrixes $\mathbf{A}_i^{i-1}$ of the kind (5). In some cases, when we visualize a contact with the support at the one end of the kinematic chain of the body, the transfer in the global coordinate system of the coordinates of the points of part of the segments is in a direction opposite to the direction of the transfer applied so far, i.e., instead of a transfer with a direction from the end segments to the basic segment, the transfer is with direction from the basic segment to the certain end segment of the kinematic chain. This means that in this case, we should apply the reversed matrix $\left[\mathbf{A}_i^{i-1}\right]^{-1}$ (Angelov, 2008). The matrix $\left[\mathbf{A}_i^{i-1}\right]_{(4\times4)}$ is not orthogonal, which means that $\left[\mathbf{A}_i^{i-1}\right]^{T} \neq \left[\mathbf{A}_i^{i-1}\right]^{-1}$, and the inverse matrix $\left[\mathbf{A}_i^{i-1}\right]^{-1}$ is determined with the expression:

$$\left[\mathbf{A}_i^{i-1}\right]^{-1} = \mathbf{A}_{i-1}^{i} = \begin{bmatrix} \left[\mathbf{G}_i^{i-1}\right]^T & -\left[\mathbf{G}_i^{i-1}\right]^T \boldsymbol{l}_i^{i-1} \\ \mathbf{0}_{(1\times3)} & 1 \end{bmatrix}. \quad (7)$$

**RESULTS**

When we have the global coordinates of the points determined for visualization, we can easily construct the anthropomorphic structure (Figure 4). Its movement provides us with a clear visual idea of the simulated exercises.

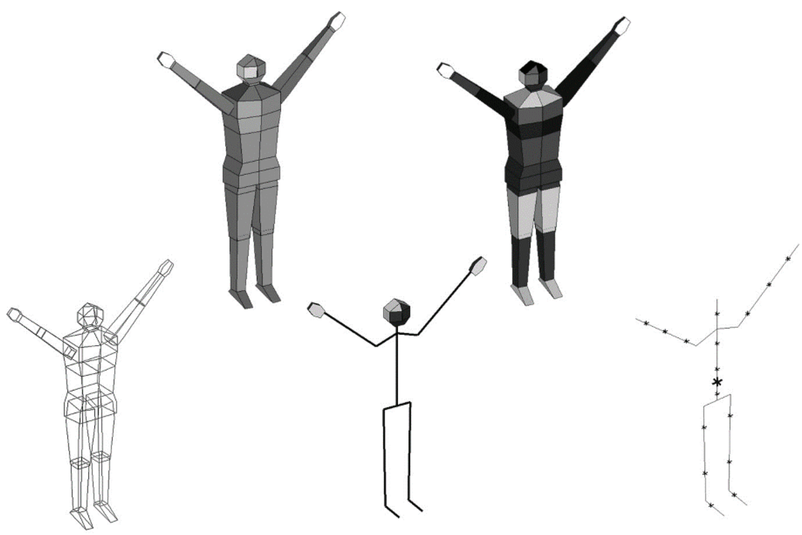

**Figure 4.** *Options for body visualization - (3D) anthropomorphic structures*

The realization of the assigned movement can be observed from different points of view by positioning "the camera" according to the specificity of the movements. We have to set the azimuth angle (horizontal rotation around the vertical axis) and the slope of the horizontal plane (Figure 5).

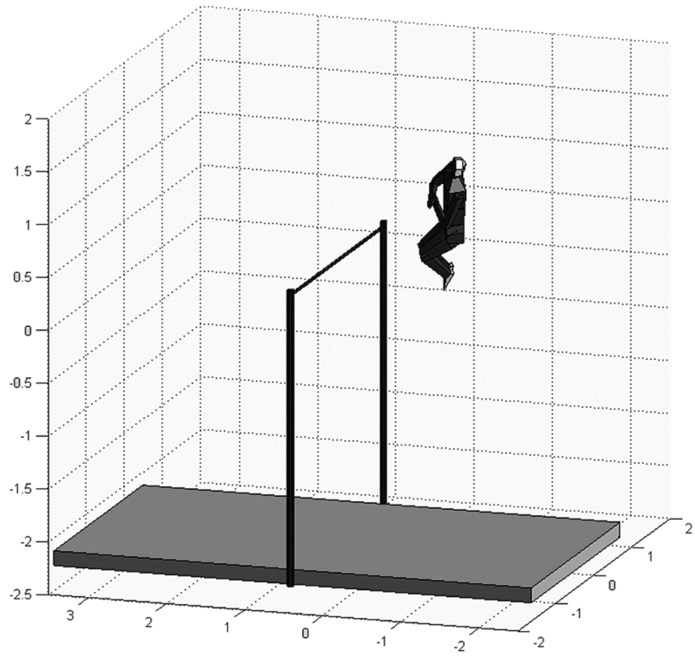


**Figure 5.** *Sample point of view when observing a simulated movement*

Our full attention is directed to the rotation components of the movement. That's why during the observations, we can neglect the parabolic movement, determined by three simple equations describing the displacement in the center of gravity. The selection of the point of view is determined by the type of movement so that we can provide as much visual information as possible about both the actions related to the rotation movements and the mechanical effects of the execution. The observation is usually made to the side (in "clear" somersaults) and to the front (at some points from the top) when the movement is a combination of rotations (Figure 6).

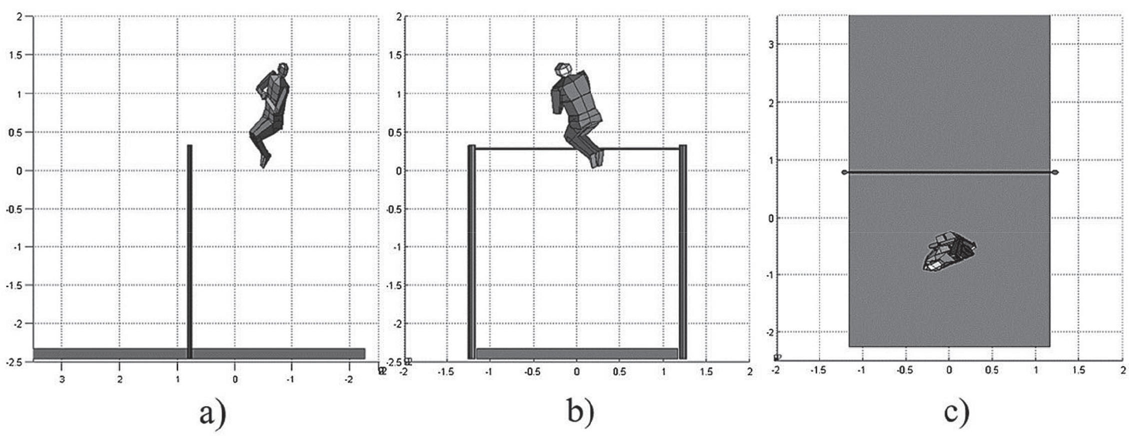


**Figure 6.** *Options of points of view depending on the observed movement: (a) from the side; (b) in front; (c) from the top*

The program module for the visualization of an athlete's movement is working in the MATLAB Computing Environment.

**DISCUSSION**

The aim of the research was to introduce a methodology for the visualization of the simulated movement based on the current results from the calculations. In visualization, we get a clear idea of the movement in the process of solving the equations of motion. The possibility to observe the movement from different points of view greatly facilitates the researcher. We can simultaneously observe the image from different viewpoints if we consider it appropriate. Figure 7 presents a sequence of images corresponding to the stages of the integration of the equations and corresponding to different positions of observation of the initial moment of the flight phase in floor exercises.

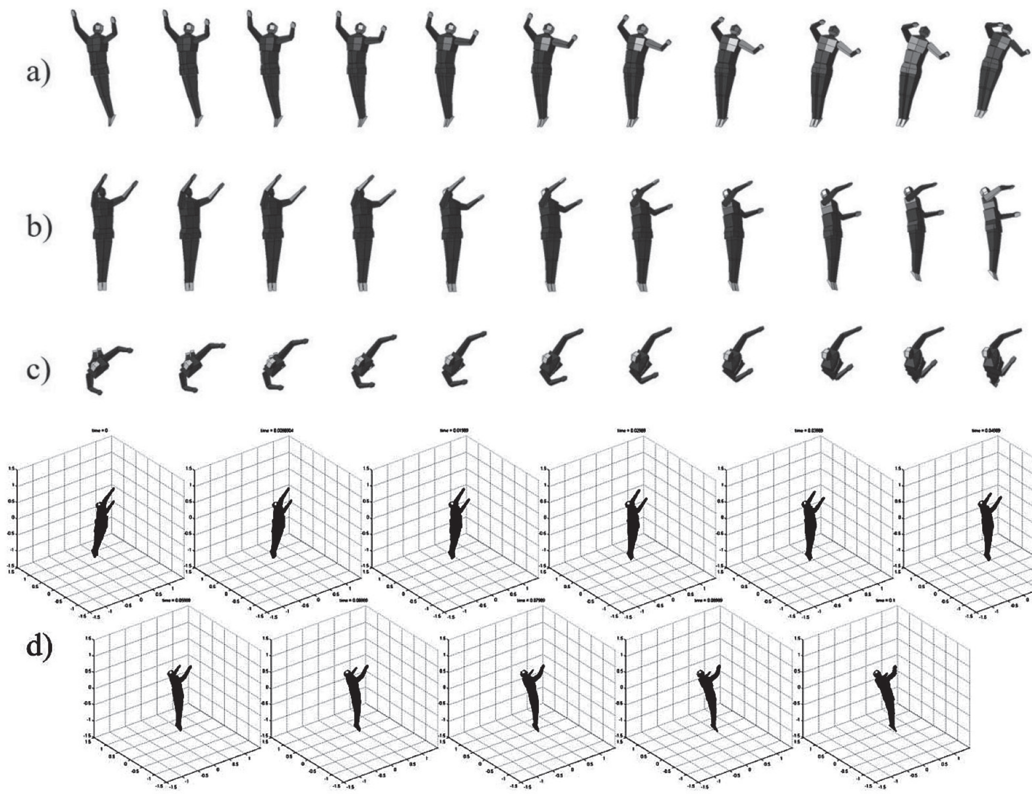


**Figure 7.** *Different points of view of the movement: a) to the side; b) to the front; c) from the top; d) from a certain angle*

To avoid the unnecessary clutter of the observed image, besides the "stopping" of the displacement along the set trajectory, the images of the apparatus and the environment can also be ignored. Thus, a researcher's attention can be focused entirely on these most important details of the execution, which are the subject of the research. The visualization of the obtained current results enables us to terminate the course of the iterations when the results (movement) are quite different from the expected ones or do not correspond to the researcher's interest. The visualization of a particular movement can be made not only with the solution of the equations upon applying the simulation model. If we have the overall coordinates (usually angle coordinates) and their change over time, we can enter these data and obtain a visual image of the movement. In this way, we can visualize new exercises, too.

We use two approaches in the control of the model (Kyuchukov, 2021). In the first approach, we first built graphs of the functions of the change in the angles over time. The curve's angle time is built with a cubic spline function (Figure 8). We view the obtained form of the curve, and then we build a differential curve based on velocity-time.

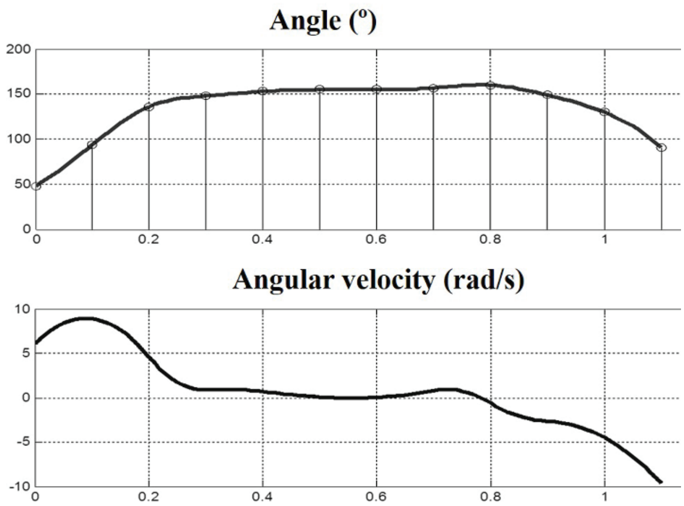


**Figure 8.** *Interpolation of the change in the angle in the shoulder joint (flexion/extension) with cubic spline function (with 12 knots)*

In the other approach, in order to gain control over the relative movements in joint angles, the time for a particular movement is divided into equal in duration subintervals (usually, the duration of the subintervals ranges from 0.04 to 0.1 sec). It is accepted that the angular velocity of each subinterval is constant and equal to the average angular velocity for the change in the angle in this subinterval. The vectors with the values of angular velocities for the different subintervals are created.

## CONCLUSION

We have designed a program module for the visualization of sports movements, which is integrated into the main program for numerical experiments, thanks to which the simulation results can be presented in a straightforward, convenient perception view. The visualization of the current results from the simulated movement contributes to the detailed analysis and facilitates the interpretation of the obtained results. The model possesses a high degree of mobility, making it suitable for surveying various movements and actions characteristic of gymnastics elements. The model can also be applied to research activities for other sports movements.

## REFERENCES

Angelov, I. V. (2008). *Matrichna mehanika: kinematika,* Avangard Prima, Sofia. *[In Bulgarian]* Ангелов, Ил. В. (2008). *Матрична механика: кинематика,* Авангард Прима, София.

Baker, R. (2011). Globographic visualisation of three dimensional joint angles. *Journal of Biomechanics, 44*(10), 1885-1891.

Bauer, W. (1985). A manually operated biomechanical model of an internally energized self-oscillatory system. *In D. Winter, R. Norman, R. Wells, K. Hayes and A. Patla (Eds.), Biomechanics IX-B, Champaign, IL, 1985*, Human Kinetics, 383-388.

Casolo, F. & Zappa, B. (1992). Computer simulation in sport didactics and coaching. *10 International symposium on biomechanics in sports, 1992, Milan, Italy*, 182-185.

Cheng, P. L. (2000). A spherical rotation coordinate system for the description of three-dimensional joint rotations. *Annals of Biomedical Engineering, 28*(11), 1381-1392.

Cheng, P. L. (2004). Joint rotation between two attitudes in the spherical rotation coordinate system. *Journal of Biomechanics, 37*(10), 1475-1482.

Cheng, P. L. (2006). Simulation of Codman's paradox reveals a general law of motion. *Journal of Biomechanics, 39,* 1201–1207.

Dallas, G. & Theodorou, A. (2020). The influence of a hurdle target point on the kinematics of the handspring vault approach run during training. *Sports Biomechanics*, *19*(4), 467-482.

Kiuchukov, I. & Kulishev, N. (2007). Vazmojnosti za precizirane na analiza na prostranstveni dvijenia. *Nauchni trudove na Rusenski universitet "Angel Kanchev",* tom 46, seria 8, 2007, 45-49. [In Bulgarian] Кючуков, Ил., Кулишев, Н. (2007). Възможности за прецизиране на анализа на пространствени движения. *Научни трудове на Русенски университет „ Ангел Кънчев"*, том 46, серия 8, 2007, 45-49.

Kiuchukov, I. & Yanev I. (2014). Application of movement visualization models during the study of gymnastic exercises. *Proceedings book, 9th FIEP European Congress and 7th International Scientific Congress „Sport, Stress, Adaptation", 2014, Sofia*, 476-479.

Kyuchukov, I. (2021)**.** Biomehanichni modeli na bezopornata faza na gimnasticheski uprajnenia s kombinirane na rotacionni dvijenia. DN disertacia, Sofia, NSA, „V. Levski". [In Bulgarian] Биомеханични модели на безопорната фаза на гимнастически упражнения с комбиниране на ротационни движения. ДН дисертация, София, НСА „В. Левски".

Engin, A. E. & Peindl, R. D. (1987). On the biomechanics of human shoulder complex - I. Kinematics for determination of the shoulder complex sinus. *Journal of Biomechanics, 20*(2), 103-117.

Peindl, R. D. & Engin, A. E. (1987). On the biomechanics of human shoulder complex - II. Passive resistive properties beyond the shoulder complex sinus. *Journal of Biomechanics, 20*(2), 119-134.

Raikova, R. (1992). A general approach for modelling and mathematical investigation of the human upper limb. *Journal of Biomechanics, 25*(8), 857-867.

Shoemake, K. (1985). Animating rotation with quaternion curves. *SIGGRAPH Comput. Graph., 19*(3), 245–254.

Stirling, L. A., Willcox, K. & Newman, D. (2010). Development of a computational model for astronaut reorientation. *Journal of Biomechanics, 43*(12), 2309–2314.

Yeadon, M. R., Atha, J. & Hales, F. D. (1990). The simulation of aerial movement - IV. A computer simulation model. *Journal of Biomechanics, 23*(1), 85–89.

Zatsiorsky, V. M., Aruin, A. S. & Seluyanov, V. N. (1981). *Biomehanika dvigatelnogo apparata cheloveka. Fizkultura i sport, Moskva.* [In Russian] Зациорский, В. М, Аруин, А. С., Селуянов, В. Н. (1981). *Биомеханика двигательного аппарата человека. Физкультура и спорт, Москва.*

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