# Virtual analysis of the athletic motion. Hurdles race

MIHAI TOFAN, SORIN VLASE, HORATIU TEODORESCU, IOAN BURCA, IOAN CANDEA
Department of Mechanical Engineering
Transilvania University of Braşov
29 Eroilor Blvd., 500036 Braşov
ROMANIA

*Abstract:* - The paper presents a kinematical model of an athlete in a hurdles race. The body of the athlete is considered a multibody mechanical system composed by 12 rigid bodies. Using kinograms obtained by the authors, an identification of the motion kinematics is performed. The results are presented as successive positions of the athlete.

*Key-Words:* - Virtual analysis, Kinematical identification, Multibody mechanical system, Kinograms, Athletic motion, Kinematic models, Hurdles race.

## 1 Introduction

The paper proposes a kinematical modeling of an athlete in a hurdles race, seen as a multibody mechanical system, interacting with the environment through the beating leg and to correct him the motion during the vault, with the aim of optimization the crossing over the hurdle.

## 2 The kinematical model of the runner

The kinematical model of the runner is presented in fig. 1. Therefore, a multibody system composed from 12 rigid elements being in interconnection through some spherical or cylindrical joints is considered. The motion of one element will be referred to the athlete's trunk and the trunk motion will be referred to an inertial reference system. In this way the motion of each segment will be described, step by step, taking into account the relative motions of the different parts of the athlete.

The model could be used for the modeling of other athletic events. In figure, the cylindrical and spherical joints of the athlete are presented. Certainly, this division is not just perfect, representing an idealization, since the cylindrical considered joints can have supplementary degrees of freedom but with small amplitude that, in this stage of the study, will be neglected.

A spherical joint allows three degrees of freedom for the articulated segment, that are general rotations with fixed point while the cylindrical joints allows one degree of freedom for the articulated segment, namely a rotation around an axis which defines the joint. The athlete's trunk may occupy any position in space, from where it results that its position in relation to an inertial reference system may be defined through six scalar parameters. In this case the system that models the runner is defined by 27 degrees of freedom being in interaction.

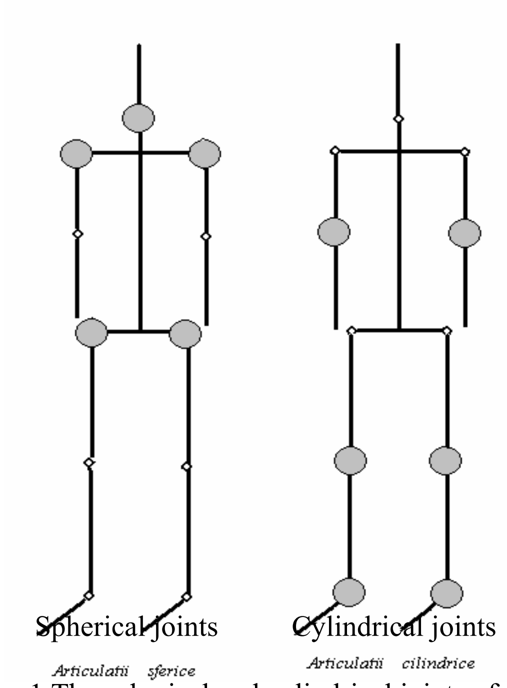



Fig. 1 The spherical and cylindrical joints of the model

A restricted condition is that the athlete should move on the horizontal track, which reduces from the number of degree of freedom of the system as long as the runner is with one leg on the track.

The contact with the track will influence the athlete's motion dynamics by the interaction that takes place between the athlete's legs and the track. In the uncoupling moment from the track and passing over the hurdle, upon the athlete will act only the weight, the position of the weight center will move in a determined manner in gravitational field and the motion of the active segments in the aim of passing over the hurdle, will determine a compensatory motion of the other segments, to observe the theorems of mechanics.

In fig. 2, the cylindrical and spherical joints and the reference systems attached to the segments connected through these kinds of joints are presented. While for the study of a segment connected through a cylindrical joint is necessary a single scalar parameter which defines the segment position, in case of a spherical joint, three scalar parameters are necessary to define the position of the mobile reference system, connected to the segment that moves. These three scalar parameters are, generally, the Euler's angles [1], [2].

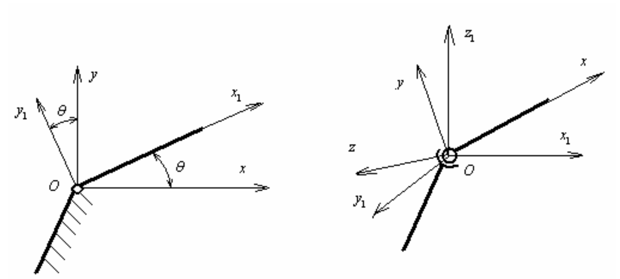


Fig. 2 The cylindrical and spherical joint

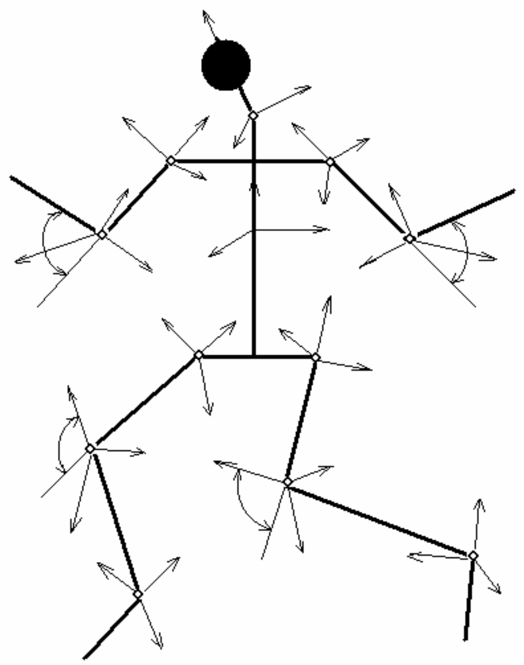


Fig. 3 The athlete's body during the event

## 3 The study of the relative motion of different segments

In case of the runner's motion, the different segments of the body belonging to arms and legs will have a relative motion against the trunk which will be considered as a non-inertial reference system from where the motions of the other parts of the body will be referred to.

The symmetry of the human body suggests such an approach. The trunk will have a three-dimensional general motion against an inertial reference system. A certain position of the runner is presented in fig. 4, where the relative positions of the reference systems attached to the mobile segments against the trunk can be noticed. In general, there are three kinds of segments: segments that belong to the right or left leg, segments belonging to the right or left arm and the head.

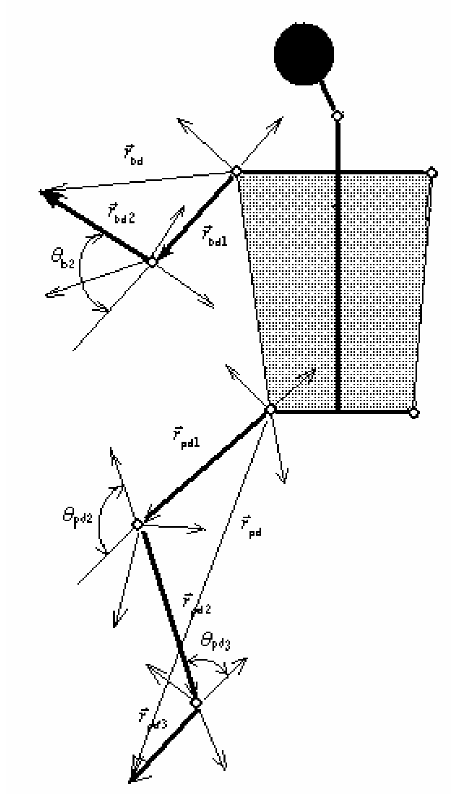


Fig. 4 The description of the final position of different segments

The easiest way is to describe the head motion against the trunk. Let us denote with $\varphi_c, \psi_c, \theta_c$ the Euler's angles that describe the motion of the reference system attached to the body. In this case, the motion of this segment is defined by the matrix:

$$[\,R_c\,] = \begin{bmatrix} r_{11c} & r_{12c} & r_{13c} \\ r_{21c} & r_{22c} & r_{23c} \\ r_{31c} & r_{32c} & r_{33c} \end{bmatrix}, \tag{1}$$

where the matrix components are:

$$\begin{aligned}
r_{11c} &= \cos\psi_c \cos\varphi_c - \sin\psi_c \sin\varphi_c \cos\theta_c\,, \\
r_{12c} &= -\cos\psi_c \sin\varphi_c - \sin\psi_c \cos\varphi_c \cos\theta_c\,, \\
r_{13c} &= \sin\psi_c \sin\theta_c\,, \\
r_{21c} &= \sin\psi_c \cos\varphi_c + \cos\psi_c \sin\varphi_c \cos\theta_c\,, \\
r_{22c} &= -\sin\psi_c \sin\varphi_c + \cos\psi_c \cos\varphi_c \cos\theta_c\,, \\
r_{23c} &= -\sin\theta_c \cos\varphi_c\,, \\
r_{31c} &= \sin\theta_c \sin\psi_c\,, \\
r_{32c} &= -\sin\theta_c \cos\psi_c\,, \\
r_{33c} &= \cos\theta_c\,.
\end{aligned} \tag{2}$$

If the Ox axis oriented along the symmetry axis of the head is considered, then the head segment is represented by the vector $\vec{r} = l_c \vec{i}$ where $l_c$ is the segment length which models the head. In this case, its position at a certain moment, in case in which the three Euler's angles are known, is given by the vector:

$$\{r_c\}_{S_o} = l_c \begin{Bmatrix} \cos\psi_c \cos\varphi_c - \sin\psi_c \sin\varphi_c \cos\theta_c \\ \sin\psi_c \cos\varphi_c + \cos\psi_c \sin\varphi_c \cos\theta_c \\ \sin\theta_c \sin\psi_c \end{Bmatrix}. \tag{3}$$

The position of the right foot can be described under the form:

$$\vec{r}_{pd} = \vec{r}_{pd1} + \vec{r}_{pd2} + \vec{r}_{pd3}\,, \tag{4}$$

or, in matrix form:

$$\{r_{pd}\} = [\,R_{\psi pd}\,][\,R_{\theta pd}\,][\,R_{\varphi pd}\,]\Big(l_{pd1}\begin{Bmatrix}1\\0\\0\end{Bmatrix} + l_{pd2}\,[\,R_{\theta pd_1}\,]\begin{Bmatrix}1\\0\\0\end{Bmatrix} + l_{pd3}\,[\,R_{\theta pd_1}\,][\,R_{\theta d_2}\,]\begin{Bmatrix}1\\0\\0\end{Bmatrix}\Big). \tag{5}$$

Similar, the position of the right forearm:

$$\{r_{bd}\} = [\,R_{\psi bd}\,][\,R_{\theta bd}\,][\,R_{\varphi bd}\,]\Big(l_{bd1}\begin{Bmatrix}1\\0\\0\end{Bmatrix} + l_{bd2}\,[\,R_{\theta bd_1}\,]\begin{Bmatrix}1\\0\\0\end{Bmatrix}\Big). \tag{6}$$

Therefore, the position of each segment can be written against the angular parameters that describe the relative motion of a segment against the other.

Similar which we defined the position for the right leg and right arm, we can define for the left leg and left arm also.

## 4 Virtual analysis

On the base of the introduced notions, a kinematical modeling and a virtual analysis of the athlete has been made. Thus, a method to analyze the athlete's motions was accomplished.

The athlete's images in motion, after kinematical identification of the athlete's parameters, will be obtained on computer. In fig. 5 and 6, a kinogram of the crossing over the hurdles is presented, kinogram used for the kinematical identification of the hurdles race. In fig. 7 – 11, the succession of the athlete's motions at the crossing over the hurdles is presented, the analysis being accomplished numerical.

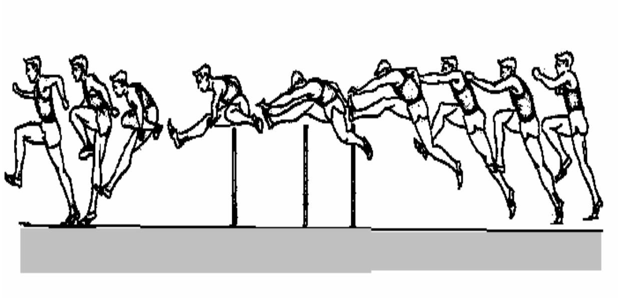


Fig. 5 The crossing over hurdle (lateral view)

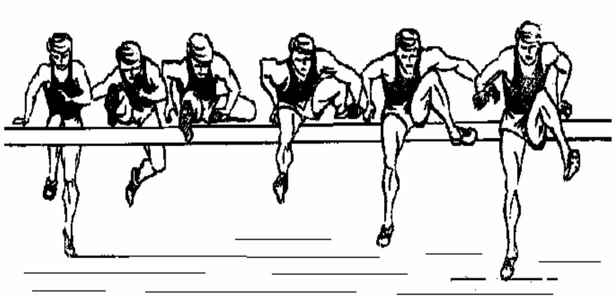


Fig. 6 The crossing over hurdle (frontal view)

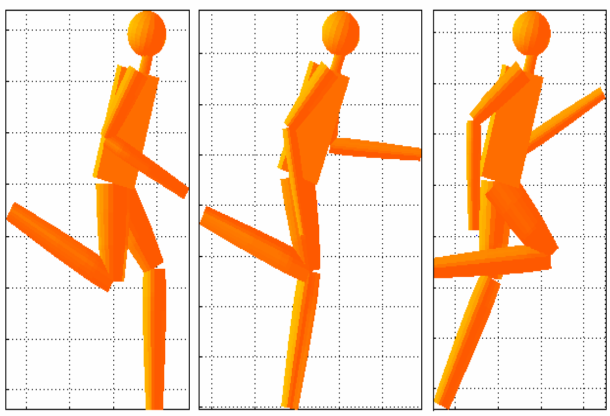
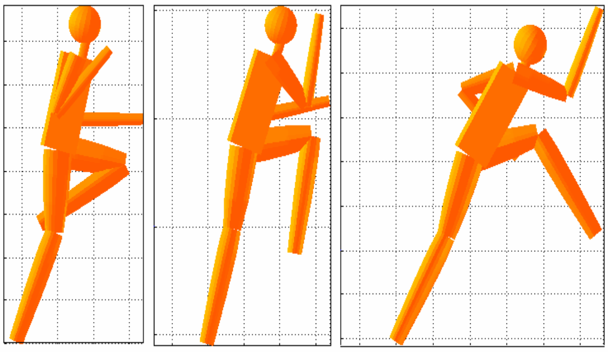
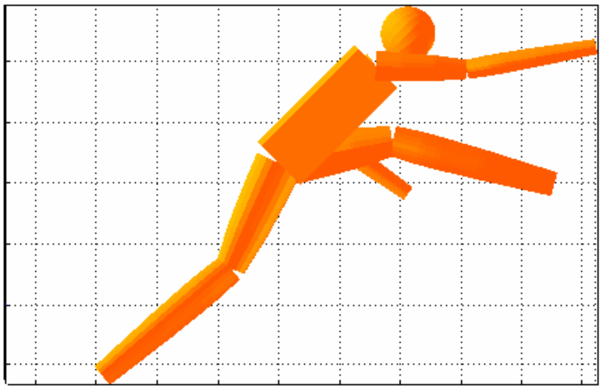


Fig. 7





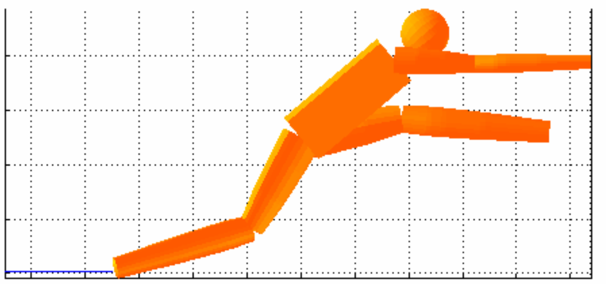


Fig. 8

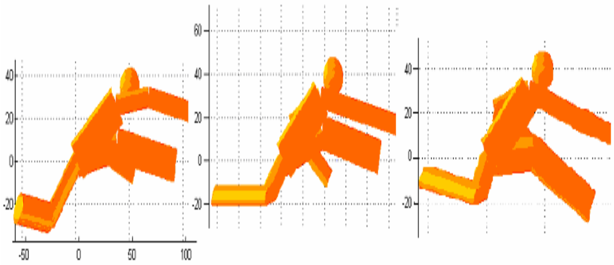


Fig. 9

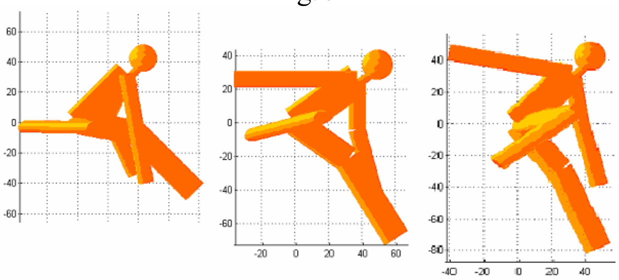


Fig. 10

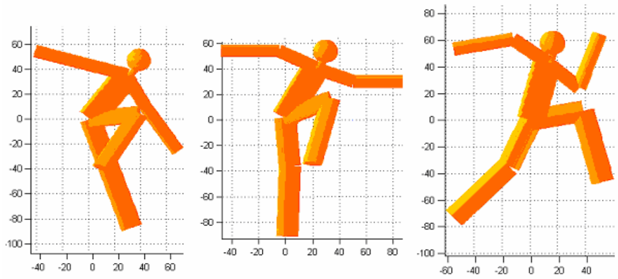


Fig. 11

## 5 Conclusions

The modeling of the athlete's body through a multibody system allows a parameterization of its motion against a number of angular parameters, so that the general motion in any of the important phases of the event can be described by the variation in time of these parameters. The authors' researches are oriented towards the determination of the variation laws of the angular parameters so that a better description of the athlete's motion in the hurdles race, which can be identified with the experimental records of such event, is obtained.

*References:*

[1] Tofan, M., *Mecanica. Cinematica,* Transilvania University of Brasov, 1993 (in Romanian).

[2] Vlase, S., *Mecanica. Cinematica,* Transilania University of Brasov, 1993 (in Romanian).

[3] Burca, I., *Atletism - analiza tehnicii probelor de atletism*, Institutul de invatamant superior, Targu-Mures, 1979 (in Romanian).

[4] Burca, I., *Atletism. Curs optional,* Institutul de invatamant superior, Targu-Mures, 1981 (in Romanian).

[5] Burca, I., Relatiile dintre executia tehnica, ritmul miscarilor si viteza de deplasare pe plat in alergarea de 400 m graduri. *Lucrare de diploma, IEFS,* Bucharest, 1970 (in Romanian).

[6] Burca, I., Relatia dintre pregatirea tehnica si cea fizica la nivelul grupei de avansati, alergatori de garduri, in cadrul Clubului Sportiv Scolar. *Lucrare grad didactic I,* 1985 (in Romanian).