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Theoretical and experimental aspects regarding long jump dynamics

Aspecte teoretice şi experimentale privind dinamica probei de săritură în lungime

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Abstract

Background. The interest in increasing sport performance has led to the development of biomechanics studies focused on human body schematic approximation as a mechanical system with joints, usually named multibody systems.

Aims. In the present paper, a multibody model of a long jump athlete is presented. Based on this model, one can find the joint reaction forces that have a key role in the human motion dynamics during different actions such as walking, jumping, gymnastics, etc. The question that arises is how joints are used during sports activities.

Methods. The model validation was based on a video recording compiled with a high speed camera during a long jump trial.

Results. Based on the visualisation of the markers' trajectories with the Adobe After Effects code, their coordinates during the long jump trial were found.

Conclusions. An experimental validation of the mechanical model was performed and the coordinates of the points of interest were found. Using these coordinates, the parameters required for a high level of performance can be established.

Keywords: biomechanics, motion analysis, long jump, theoretical model.

Rezumat

Premize. Interesul pentru sporirea performanţelor sportive a dus la dezvoltarea unor studii de biomecanică, în care rolul principal îl are reproducerea schematică a organismului uman, abordat din punct de vedere al unui sistem mecanic cu legături (cu denumirea actuală uzuală de sistem multicorp).

Obiective. În acest articol este prezentat un model multicorp al săritorului în lungime. Pe baza acestui model pot fi determinate forţele de reacţiune din articulaţii, care joacă un rol important în dinamica mişcărilor umane, precum: mersul, săriturile, exerciţiile de gimnastică etc.

Metode. Validarea modelului se bazează pe o serie de înregistrări video ale unor atleţi în timpul executării probei, cu ajutorul unei camere video de mare viteză.

Rezultate. Pe baza urmăririi traiectoriei markerilor, cu programul Adobe After Effects, au fost obţinute coordonatele acestora în timpul executării săriturii.

Concluzii. S-a reuşit validarea experimentală a modelului mecanic, fiind determinate coordonatele punctelor de interes. Pe baza acestor coordonate, sunt stabiliţi parametri utili îmbunătăţirii performanţelor sportive.

Cuvinte cheie: biomecanică, analiza mişcării, săritura în lungime, model teoretic.

Introduction

Nowadays, at global level, sport becomes more relevant each day. Severe competition between athletes has induced a change in performance achievement, which cannot be based only on human driving force. In this context, coaches have to acquire the latest knowledge for the improvement of the technique of execution.

The long jump can be considered as one of the most natural athletic trials, due to the bodily qualities developed, the required spontaneity of movements, and to its beauty, all these elements involving the improvement of technique and its development without hindrance.

The long jump with run-up represents, by the involved motions, an acyclic action: the long jump proper, in which the sequence of movements does not repeat, has a start and an end (Gevat et al., 2007).

The long jump phases, in the order of their succession, are as follows (Burcă et al., 2010; Hay et al., 1990; Ionescu-Bondoc, 2007; Mihăilă et al., 2008): run-up, take-off, flight and landing. Between these phases, there are conditioning ratios, but the share of each phase in performance achievement is determined by the specific nature and purpose of jumping.

The use of linked mechanical systems known as multibody systems for human motion analysis becomes a

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usual method due both to biomechanics development and virtual modelling facilities.

Various models, methods, applications and solutions, presented in the literature, come mostly from industrial applications, but can be found in many applications of human movement studies.

In the most used dynamic representations, multibody models often consist of sets of minimum levels of generalized coordinates, and the forces from the joints (unused reaction forces of the intrinsic constraint model) are excluded from calculation; therefore, in order to determine these forces of reaction from the joints, a new model is required and numerical procedures are difficult to calculate (Schiehlen, 2006).

When dealing with small bodies, motion equations can be obtained through manual calculations, while for more complicated systems or for checking the results, specialized software for multibody systems such as NEWEUL should be used (Kreuzer et al., 1991).

To solve the problem of the way in which joints are loaded during routine activities or sports, it is necessary to consider a mathematical model of dynamics of human body and its use to determine reaction forces from joints, using numerical simulation (Eberhard et al., 1999).

Two of the most widely used multibody system examples in sports motion analysis are presented below (Figs. 1 and 2).

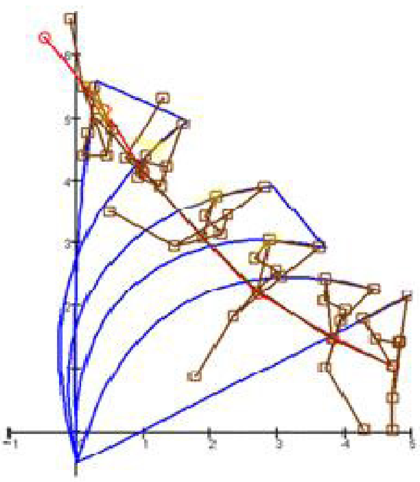


Fig. 1 – Identification of pole vault kinematics (Micu, 2006).

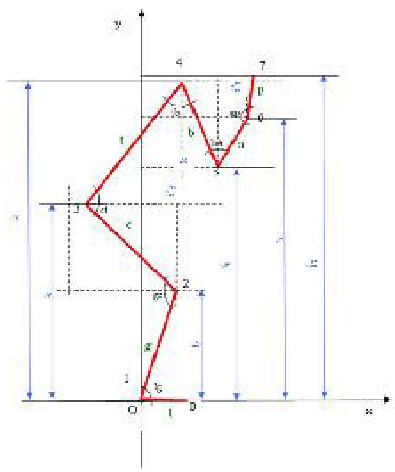


Fig. 2 – Basketball players' body segments (Haba, 2006).

The proposed models are used in motion analysis based on differential equations to find the joint force, to optimise different motion phases, etc.

As part of the present research work, a plan template model that contains 12 segments of a human body was taken into consideration (Fig. 3).

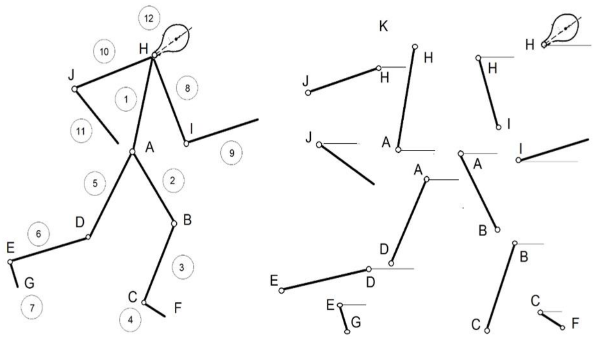


Fig. 3 – The jumper model made of segments.

Considering the first segment, the kinematic conditions are:

$$\begin{cases} x_1 = x_A + c_1 l_1 \cos\alpha_1 ; \\ y_1 = y_A + c_1 l_1 \sin\alpha_1 . \end{cases} \quad (1)$$

By deriving the equations from (1), both mass centre velocities (2):

$$\begin{cases} \dot{x}_1 = \dot{x}_A - c_1 l_1 \omega_1 \sin\alpha_1 ; \\ \dot{y}_1 = \dot{y}_A + c_1 l_1 \omega_1 \cos\alpha_1 , \end{cases} \quad (2)$$

and accelerations are obtained:

$$\begin{cases} \ddot{x}_1 = \ddot{x}_A - c_1 l_1 \varepsilon_1 \sin\alpha - c_1 l_1 \omega_1^2 \cos\alpha_1 ; \\ \ddot{y}_1 = \ddot{y}_A + c_1 l_1 \varepsilon_1 \cos\alpha - c_1 l_1 \omega_1^2 \sin\alpha_1 . \end{cases} \quad (3)$$

Based on the force diagram presented in Fig. 4, the following equilibrium equations can be written:

$$\begin{cases} X_{A1} + X_{H1} = m_1 \ddot{x}_1 ; \\ Y_{A1} + Y_{H1} - G_1 = m_1 \ddot{y}_1 ; \\ M_1 - Y_{A1} c_1 l_1 \cos\alpha_1 + X_{A1} c_1 l_1 \sin\alpha_1 + Y_{H1}(1-c_1) l_1 \cos\alpha_1 - X_{H1}(1-c_1) l_1 \sin\alpha_1 = J_1 \varepsilon_1 \end{cases}$$

(4)

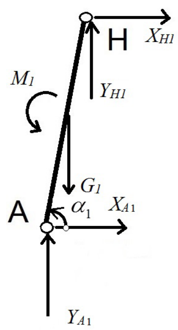


Fig. 4 - Force diagram of Segment 1.

By combining equations (3) and (4), the dynamic equations of the segment are obtained. The approach used for the first segment is applied to all the 12 segments of the human body. Based on the above concept, a system of 36 differential equations can be obtained, which describes the motion of the whole system.

To solve the equation system generated by the above mechanical model, it is necessary to consider some input data that can be obtained by experimental set-up.

The proposed model of the jumper body was validated by an experimental test consisting of data video recording with a high speed camera (AOS X - PRI).

Hypothesis

In this paper, a theoretical and experimental model used for take-off jump analysis is proposed. The jumper model is based on the above presented multibody concept.

Material and methods

Research protocol

Each athlete was informed of the following aspects: the nature of the research, the fact that the data retrieved will be used strictly for research purposes, and at the end, a consent form to participate in experimental research was signed by each athlete and each coach.

a) *Period and place of the research*

These experimental recordings were performed during the summer camp training of the athletics team in the national sports complex Poiana Brasov, for a period of two weeks.

b) *Subjects and groups*

Four international high-performance long jump athletes were considered for the present study: two females and two males. The four athletes were members of the Romanian National Athletics Team and they had different jumping techniques.

c) *Tests applied*

Coloured markers were attached on the body of each athlete (Fig. 5). The attachment points were established considering both the mechanical model and the suggestions and acceptance of the trainers. All markers were placed on one side (the same where the video camera was placed), the video recorded data being later used for motion trajectory analysis (Mihălcică et al., 2014a).

Fig. 5 - Marker attachment.

d) *Statistical processing*

Each jumper had to do 10 jumps and images were recorded at a resolution of 800x600 pixels at 500 frames/s.

At the same time, based on marker position recording, accelerations and velocities can be found using inverse kinetics. By analysing the video recordings of markers, the geometrical dimensions of the segments and the angles between them can be established.

Results

The code used to obtain experimental data was Adobe After Effects. This application was used to visualize the main motion trajectory, although its main use is for professional video editing and visual effects creation (Christiansen et al., 2007). Fig. 6 shows the trajectory of the mass centre of the jumper.

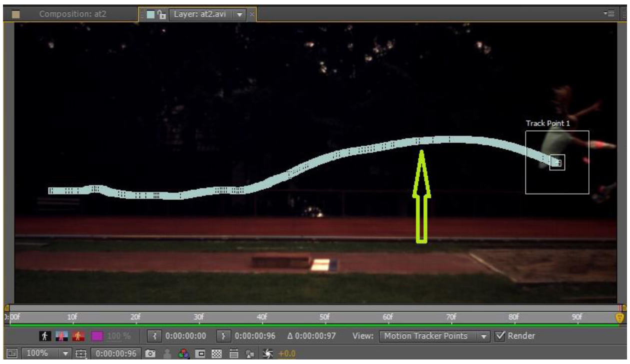
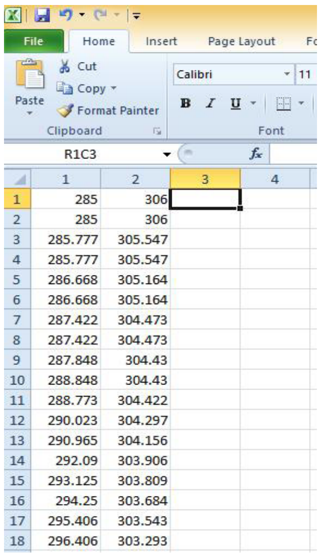


Fig. 6 - Marker motion trajectory in Adobe After Effects.

Since Adobe After Effects is not specially designed for motion analysis, this application does not achieve export of automatic marker coordinates, which need to be exported in the desired format (Mihălcică et al., 2014b). Thus, the recorded experimental data were exported in EXCEL (Fig. 7).



	1	2	3	4
1	285	306		
2	285	306		
3	285.777	305.547		
4	285.777	305.547		
5	286.668	305.164		
6	286.668	305.164		
7	287.422	304.473		
8	287.422	304.473		
9	287.848	304.43		
10	288.848	304.43		
11	288.773	304.422		
12	290.023	304.297		
13	290.965	304.156		
14	292.09	303.906		
15	293.125	303.809		
16	294.25	303.684		
17	295.406	303.543		
18	296.406	303.293		

Fig. 7 Marker positions exported in EXCEL.

The converted EXCEL data were imported in MATLAB code; using its facilities, an analysis of the last step of the run-up approach, of take-off and the start of flying through the air was performed (Mihălcică et al., 2014b; Guiman et al., 2014). Thus, a number of parameters (geometric and mechanical) leading to jumper plan model validation were identified.

Discussions

The above proposed method is useful due to: portability of the system, the fact that it is easy to use by any person with a minimum of computer knowledge, and the software is easy to use compared to other dedicated codes.

It is necessary to mention that the ideal environment for recording is the outdoor stadium, where light is natural, which is preferred during video recording, and in indoor experiments, additional light sources are needed. The system can be easily applied to the proposed or similar research, while considering the use of different data processing codes is time-expensive.

While data recording requires laptop equipment that can have a battery, for the high speed video camera, a stationary source of electricity is needed, considering that the battery life is very poor.

Conclusions

1. The considered theoretical model with 12 segments may very well shape the body of the jumper. Based on the considered multibody model, a system of 36 differential and algebraic equations was obtained. The mathematical system consists of 24 unknown joint forces and 12 unknown independent coordinates. By removing the reactions, a 12 differential equation system is obtained.

2. The theoretical model was validated by the proposed capture system, which provides valuable information that can lead to obtaining motion laws for independent coordinates, and inverse dynamics can be applied to determine the forces and moments that occur in the human system studied during jumping.

3. The presented theoretical model can be used as a basis for optimising the performance of each jumper taking into consideration human driving forces.

Conflicts of interests

There are no conflicts of interests.

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