
ЗДОРОВ'Я ЛЮДИНИ, ФІТНЕС І РЕКРЕАЦІЯ. ФІЗИЧНЕ ВИХОВАННЯ РІЗНИХ ГРУП НАСЕЛЕННЯ. ФІЗИЧНА ТЕРАПІЯ, ЕРГОТЕРАПІЯ

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DIAGNOSTICS OF HUMAN MOTOR FUNCTION IN PHYSICAL REHABILITATION

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Анотація. Використання технології біомеханічного відеокомп'ютерного аналізу є ефективним у діагностиці порушень рухової функції людини. Більшість комп'ютерних програм, які використовуються у фізичній реабілітації, є засобами автоматизації обчислень показників фізичного стану, водночас проблема розробки прикладного програмного забезпечення комп'ютеризованих вимірювальних систем для оперативного й об'єктивного аналізу рухових дій людини залишається актуальною. *Мета.* Розробити програмне забезпечення біомеханічного відеокомп'ютерного аналізу рухової функції людини у фізичній реабілітації.

Методи. Біомеханічний відеокомп'ютерний аналіз кінематичних характеристик рухових дій людини.

Результати. Розроблено прикладне програмне забезпечення «БіоВідео», що включає чотири модулі: 1) конструювання моделей опорно-рухового апарату людини; 2) визначення координат точок відносно соматичної системи відліку; 3) розрахунок біомеханічних характеристик рухової дії (програмні можливості модуля дозволяють розраховувати локалізацію центрів мас біоланок і загального центру мас тіла людини); 4) побудова біокінематичної схеми тіла людини за відеограмою рухових дій з визначенням траєкторій руху центрів суглобів, центрів мас біоланок і загального центру мас тіла людини. У покадровому та фазовому аналізах визначаються такі біомеханічні характеристики: горизонтальна, вертикальна та результуюча лінійні швидкості загального центру мас і центрів мас суглобів тіла людини; амплітуда кутів суглобів та кутова швидкість біоланок тіла спортсмена; часові характеристики; потенційна, кінетична, повна енергії окремих біоланок і всього тіла людини. Програмне забезпечення «БіоВідео» призначене для отримання якісної і кількісної інформації про рухову функцію людини, яка служить основою для розробки реабілітаційних програм. Ефективність розробленого програмного забезпечення «БіоВідео» у діагностиці рухової функції людини підтверджена клінічними дослідженнями.

Ключові слова: біомеханічний аналіз, кінематичні характеристики, рухова дія, реабілітація, програмне забезпечення.

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Abstract. The use of biomechanical video computer analysis technology is effective for diagnosing human motor disorders. Most computer programs used in physical rehabilitation are the means of automating the calculation of physical indices, while the problem of developing application software for computerized measurement systems for rapid and objective analysis of human motor actions remains relevant. *Objective.* Develop software for biomechanical video-computer analysis of human motor function in physical rehabilitation.

Methods. Biomechanical video-computer analysis of kinematic characteristics of human motor actions.

Results. The «BioVideo» application software, which includes four modules has been developed: 1) designing models of human locomotorium; 2) determining the coordinates of points relative to the somatic frame of reference; 3) calculation of biomechanical characteristics of motor action (software capabilities of the module allow to calculate the localization of the centers of mass of biolinks and the total center of mass of the human body); 4) construction of a biokinematic scheme of the human body according to the videogram of motor actions with determination of trajectories of the centers of joints, centers of masses of biolinks and the general center of masses of a human body. The following biomechanical characteristics are determined in frame-by-frame and phase analyzes: horizontal, vertical

and resulting linear velocities of the general center of mass and centers of mass of joints of the human body; the amplitude of the angles of the joints and the angular velocity of the biolinks of the athlete's body; time characteristics; potential, kinetic, total energy of individual biolinks and the whole human body. The «BioVideo» software is designed to obtain qualitative and quantitative information about human motor function, which is the basis for the development of rehabilitation programs. The effectiveness of the developed software «BioVideo» in the diagnosis of human motor function has been confirmed by clinical studies

Keywords: biomechanical analysis, kinematic characteristics, motor action, rehabilitation, software.

Introduction. Among the non-contact control methods of human motion actions, biomechanical analysis technology with motion capture which based on video is one of the most promising methods for recording human motion function [2, 6, 19]. The analysis of scientific and methodological sources and summarization of the best practical experience make it possible to conclude that objective data on human motor actions, obtained with the help of biomechanical video-computer technology, can be effectively used for the diagnosis of disorders of human motor function in physical rehabilitation [5, 13, 17].

The technology of biomechanical video-computer analysis includes two main stages: shooting with a camcorder and processing of the received video-grams with the help of specialized software. The error in determining the temporal characteristics of the movement does not exceed the duration of the time interval between frames. For example, when shooting with an amateur camera at 25 frames per second, this error would be $1/25 \text{ s} = 40 \text{ ms}$. Two or three-dimensional images of human movement are created using the captured images. After that, each moment of motion (with a sample rate of 40 ms) can be viewed at any angle. With the advancement of video technology, measurement accuracy is steadily increasing [7, 10, 11]. Video systems have now allowed both high resolution and high frequency shooting (up to 500,000 frames per second).

Most computer programs that used in physical rehabilitation are means of automating the calculation of physical condition indices and maintaining databases [3, 18]. There are very few computerized measurement systems that are tools for objective analysis of a person's motor function in a short time [8, 9, 12].

The purpose of the research is to develop software for biomechanical video-computer analysis of human movements in physical rehabilitation.

Material and methods: biomechanical video-computer analysis of kinematic characteristics of human motor actions.

Motion of a patient with knee injury was recorded using a Sony Handicam DCR-VX2100E digital camera (25 frames per second) in the sagittal plane. The optical axis of the camera lens coincided with the corresponding axis of patient rotation. As a model of the human musculoskeletal system the 14-segmented, branched kinematic chain was used, the coordinates of its links correspond to the coordinates of the bio-links position of the human body in the space by geometric characteristics, and the reference points – to the coordinates of the centers of the main

joints (20 points were selected: 1 – CM of the head; 2 – jugular notch; 3 – center of the right shoulder; 4 – center of the left shoulder; 5 – center of the right elbow joint; 6 – center of the left elbow joint; 7 – center of the right radial wrist; 8 – center of left radial wrist; 9 – end of right wrist; 10 – end of left wrist; 11 – center of right hip joint; 12 – center of left hip joint; 13 – center of right knee; 14 – center of left knee; 15 – center of the right ankle; 16 – center of the left ankle; 17 – end of the right heel; 18 – end of the left heel; 19 – end of the right toe; 20 – end of the left toe. The general center of mass of the human body is determined by the position of the bio-link's CM. The CM of human body bio-links is determined with the coefficients Bernstein [1].

Results. The Department of Biomechanics and Sports Metrology of the National University of Ukraine on Physical Education and Sports has been working on the development of biomechanical video-computer analysis systems since the 1980s [2, 4]. As a result of the research, application software for biomechanical video-computer analysis «BioVideo» was developed, which was intended for obtaining kinematic and dynamic characteristics of human motion by video [14, 15]. The «BioVideo» hardware consists of a video recording device (digital or analog camcorder, digital photo camera with video recording mode) and a personal computer.

The development of the specialized «BioVideo» software used the integrated environment of Object-based and Event-driven Microsoft Visual Basic programming language with a graphical interface. Programming in Visual Basic 6.0 is a combination of visually arranging components or controls on a form, specifying attributes and actions for those components, and writing additional lines of code for more functionality. The source data for the «BioVideo» application are files of single-plane human motion in .BMP, .DIB, .WMF, .EMF, .GIF, .JPG, .JPEG formats. «BioVideo» allows obtaining biomechanical characteristics of both individual bio-links and the total human body in each frame and in separate phases of the motor action. The «BioVideo» software includes four modules:

- module for designing models of the human musculoskeletal system (MSS); the module allows you to create multi-link MSS models with up to 100 reference points;
- module for determining the coordinates of points relative to the somatic system of reference;
- module for calculating the biomechanical characteristics of locomotor actions according to the coordinates of the human MSS model; the software capabilities of the module allow you to calculate

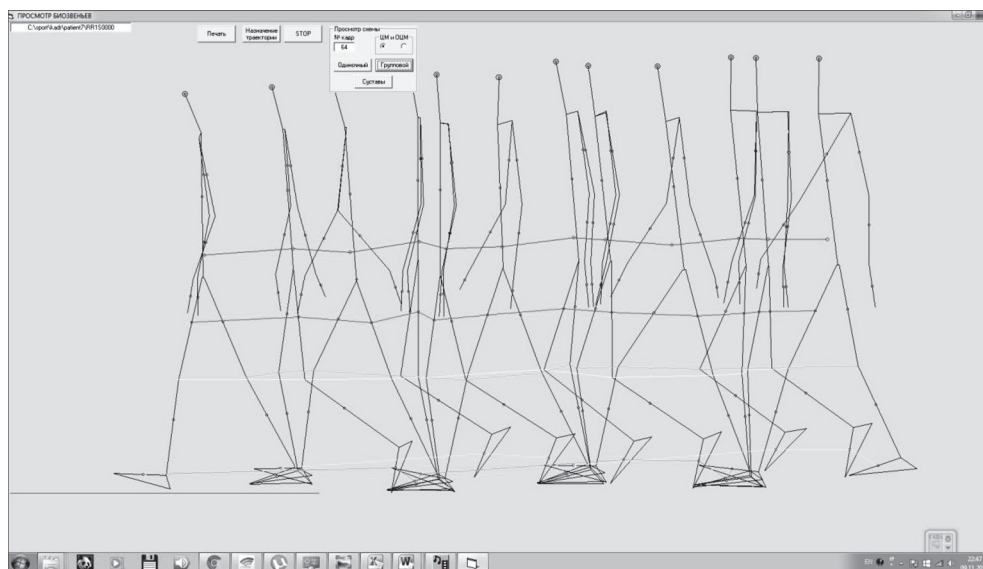


Figure 1 – The bio-kinematic scheme of patient’s gait with injury of the left knee joint

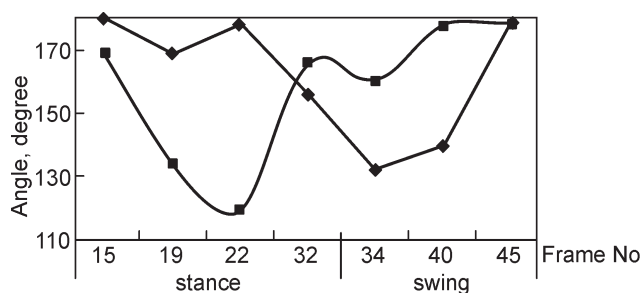


Figure 2 – Goniogram of knee:
 ◆ – left; ■ – right

the localization of the bio-link’s CM and the human body’s GCM;

- module for constructing the bio-kinematic scheme (BKS) of the human body according to a motion videogram with the definition of the trajectory of the joint center’s motion, of the bio-link’s CM and of the human body’s GCM.

You can analyze the motion action by video frames with “BioVideo” software under any speed acceptable for the hardware, since the user is able to set this speed programmatically (it is taken into account in «BioVideo» when determining every quantitative characteristic).

The “BioVideo” software is used to determine the following biomechanical characteristics: horizontal, vertical and resulting linear velocity of the GCM and of the CM of the joint; the amplitude of angles and angular velocity of human body’s bio-link; the potential, kinetic, and total energy of separate bio-link and the total human body. The reading of coordinates of a human body’s point is made by stop-frame of video shooting with “BioVideo” software.

In Figure 1, a gait bio-kinematic scheme of patient with a left knee trauma is presented. This one is built with «BioVideo» software.

The kinematic characteristics of the phase structure of the patient’s gait with left knee injury are showed in the Table 1. Those were obtained by “BioVideo” module for biomechanical characteristics calculation.

In Figure 2, the goniogram of the patient’s right and left knee joint is presented.

Discussion. The optical tracking technology, also known as optical motion capture, makes it possible to measure patient’s motion for the purpose of diagnosis, treatment assessments, or monitoring. Optical marker-based tracking is the most accurate method today [7, 10, 16]. One of the most advanced modern video computer systems «Qualisys», Sweden (<https://www.qualisys.com>) is used today in the National University of Ukraine on Physical Education and Sports. In the “Qualisys” system, reflective markers are placed on the measurement object, which are illuminated by infrared rays (up to 1000 Hz). The reflected light from the markers hits the ProReflex MCU camera, which is connected to the computer. Shooting speed: 1–240 Hz (MCU 240) and 1–1000 Hz (MCU 1000). The software allows analyzing the movement in detail (in 2 and 3 coordinate space). Quantitative biomechanical characteristics: kinematic and dynamic, as well as posture and balance are calculated.

The “BioVideo” system can be used to find and prevent injuries by measuring on patient’s motion. Along with simplicity and markerless, the advantage of the “BioVideo” software is that human movement is recorded by any video or photo camera directly at any location – hospital or home, while those systems as “Qualisys” can only be used in laboratory conditions [17, 18, 20]. Also, the disadvantage of imported video analyzer systems is their relatively high price (and not only for Ukraine).

Table 1 – Kinematic characteristics of patient’s gait with trauma of the left knee joint

Lmb	Temp, steps/min	Cycle length, m	Phase	Duration, s	Phase	Duration, s	Instant in time	Frame Number	Step length, m	GCM's speed, m/s	Angle of right knee, degree			Angle of left knee, degree		
											Hip	Knee	Foot	Hip	Knee	Foot
Left leg	93,75	1,02	Stance	0,88	Double stance	0,24	Contact with the left heel	00	0,49		176,9	165,5	83,8	147,6	171,0	99,6
							Ipsilateral right toe-off	06		0,81	177,4	127,5	116,5	164,8	166,9	95,8
							Swing left leg approaches vertical	09		0,80	150,2	102,3	98,3	172,0	173,4	95,2
							Double stance	0,24	Contact with the right heel	16	0,51	0,78	139,3	158,8	101,3	172,4
			Swing	0,40	Ipsilateral left toe-off	22		0,91	156,3	154,7	97,1	174,0	124,2	112,1		
			Swing right leg approaches vertical	25		0,86	170,2	163,9	95,0	157,3	110,6	99,1				
	93,75	0,93	Stance	0,88	Double stance	0,20	Contact with the left heel	32	0,49	0,84	161,8	173,7	84,2	159,6	174,2	91,0
							Ipsilateral right toe-off	37		0,92	166,4	136,2	101,4	172,2	164,6	93,5
							Swing left leg approaches vertical	40		0,76	171,4	114,2	100,3	0,1	169,0	91,8
			Double stance	0,24	Contact with the right heel	48	0,46	0,71	150,1	161,5	97,6	164,7	174,2	82,2		
Swing			0,40	Ipsilateral left toe-off	54		0,78	167,7	161,0	94,7	178,4	131,6	116,0			
				Contact with the left heel	64	0,46	0,73	174,3	81,1	166,2	174,5	95,2	157,8			

Conclusions:

1. Analysis of scientific and methodological references, synthesis of best practices of leading experts and own pedagogical observations had to conclude that biomechanical analysis is one of the main elements that can be used to diagnose human motor function in physical rehabilitation for the development of correction programs, and individual and group (age) programs of motor rehabilitation in the system of medical and physical-health institutions.

2. The research resulted in the development of

automated “BioVideo” system with application software for the measurement and analysis of human movements.

3. The effectiveness of “BioVideo” software in the diagnosis of human motor function has been confirmed by practical studies.

Prospects for further research include the development of software for determining the power and mass-inertial characteristics of human motion.

Conflict of interest. The authors declare that there is no conflict of interest.

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