VIRTUAL MODELING AND SIMULATION OF THE COLLISION OF TWO ATHLETES IN SPORTS

ВІРТУАЛЬНЕ МОДЕЛЮВАННЯ ТА ІМІТАЦІЯ ЗІТКНЕННЯ ДВОХ СПОРТСМЕНІВ У СПОРТІ

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With the help of a specialised software used in mechanical engineering, there was created an independent modulus to simulate the impact between two human bodies. Thus, considering the material properties afferent to human body, the initial speeds, the restitution and friction coefficients, the created modulus may specify the values of velocities and accelerations after the impact, of the bodies, the meaning of these velocities and accelerations and maximum stresses that occur, as well the location of these stresses. The theoretical values of velocities were compared to the experimental values, being done the corresponding corrections to validate the software modulus. The collision of two athletes can be viewed from two perspectives, namely: in terms of sports performance and in terms of the traumas that can occur in athletes. From a performance perspective, impact force is important in freestyle wrestling or Greco-Roman wrestling, sumo, rugby, etc., and can make the difference between winner and loser. In contrast, the traumas caused by the impact force can sometimes be severe enough, requiring long periods of hospitalization and recovery. The virtual simulation, based on the suitable software, allows the coach and the technical staff to prepare the athletes so as to either obtain a certain impact force, or to diminish the impact force with the opposing athletes. The software module was tested for the collision of two athletes in the game of rugby. Thus, using a rugby team from Iasi, we simulated the collision of two athletes each in a gym and we determined experimentally, by videographic method, the impact speeds which, then, we compared with those obtained with the help of software module. The initial impact velocities used in the software module were those determined experimentally. The values obtained for the velocities of human bodies after collision, using the software module, by simulation, are very close to those obtained by experimental measurements. For the future, we aim to improve this software module by performing experimental measurements during sports competitions and comparing them with the values determined by simulation.

Key words: *biomechanics, velocity, force, impact, performance, injury.*

За допомогою спеціалізованого програмного забезпечення, яке використовується в машинобудуванні, було створено незалежний модуль для імітації удару між двома людськими тілами. Таким чином, враховуючи властивості матеріалу, властиві тілу людини, початкові швидкості, коефіцієнти відновлення і тертя, створений модуль може задавати значення швидкостей і прискорень після удару, тіл, значення цих швидкостей і прискорень і максимальних напружень. які виникають, а також розташування цих напружень. Теоретичні значення швидкостей порівнювали з експериментальними, проводячи відповідні виправлення для перевірки програмного модуля. Зіткнення двох спортсменів можна розглядати з двох позицій, а саме: з точки зору спортивних результатів і з точки зору травм, які можуть виникнути у спортсменів. З точки зору продуктивності, сила удару важлива у вільній боротьбі або греко-римській боротьбі, сумо, регбі тощо, і може зробити різницю між переможцем і переможеним. Навпаки, травми, викликані силою удару, іноді можуть бути досить серйозними, що вимагають тривалих періодів госпіталізації та відновлення. Віртуальне моделювання, засноване на відповідному програмному забезпеченні, дозволяє тренеру та технічному персоналу підготувати спортсменів так, щоб або отримати певну силу удару, або зменшити силу удару зі спортсменами-суперниками. Програмний модуль тестували на зіткнення двох спортсменів у грі регбі. Так, за допомогою команди з регбі з Яссів ми змоделювали зіткнення двох спортсменів у спортзалі та експериментально визначили відеографічним методом швидкості удару, які потім порівнювали з отриманими за допомогою програмного модуля. Початкові швидкості удару, використані в програмному модулі, були визначені експериментально. Значення, отримані для швидкостей людських тіл після зіткнення за допомогою програмного модуля, шляхом моделювання, дуже близькі до отриманих при експериментальних вимірюваннях. На майбутнє ми прагнемо вдосконалити цей програмний модуль, проводячи експериментальні вимірювання під час спортивних змагань та порівнюючи їх із значеннями, визначеними за допомогою моделювання.

Ключові слова: *біомеханіка, швидкість, сила, удар, продуктивність, травма.*

Introduction

The issue of the collision of two athletes started from the studies carried out in the automotive engineering related to the impact between a human body and an inert rigid body. Thus, the impact between the head of an athlete without a helmet and an another body was analysed using finite element analysis [1; 2; 3], to observe the distribution of mechanical stresses in the skull. Kinematic analysis for the impact of the human head and another body can be performed with Model-Based Image-Matching (MBIM) method [4; 5]. There can be serious consequences for human head trauma, including concussion [6; 7; 8; 9].

The mathematical modeling of the impact during the game of two human subjects, performed on the basis of the law of conservation of mechanical momentum and restitution coefficient, allows the calculation of athletes' speeds after collision and the average percussive force [10; 11; 12]. The average percussive force is related to the variation of the

mechanical impulse in the collision, it being dependent on the mass of the subject and on the velocities of the subject immediately before and after the collision. Characteristic for the movement during the collision is the sudden variation of the velocity in the short time interval that lasts this phenomenon. As a consequence, the magnitudes that characterize motion (respectively momentum and kinetic energy) also vary greatly. Collision of two objects or two human subjects is a process taking place in a very short time. During this action, on the two human subjects a very big percussion force acts, representing the force of reciprocal pressing of the impacting bodies. During the impact, the percussion force is subjected to very big variations. The exact mathematical law of variation is relatively difficult to evaluate. Usual calculus is using an average percussion force, that is defined as a percussion force causing the same effect as the real percussion force.

Graphic software module

To represent the collision of two athletes, a generic model of a human subject was first created, using a CAD program of 3D construction of objects. This model can be customized, depending on the general body dimensions of the athlete, as well as the weight or biomechanical characteristics of "material" of the body (mass density, average modulus of elasticity, Poisson's ratio, etc.).

With the help of the equations of motion, two bodies have been defined that approach each other, with different velocities and that collide.. As initial data for the impact, the velocities before the collision, the relative position between the two athletes, the coefficients of friction with the ground and the restitution coefficient to collision between the two subjects were introduced.

As output data, the graphics module provides the following information for each athlete:

• athletes' velocities after the collision, these being given both in terms of the x, y and z components, and in terms of the resulting velocity;

• athletes' accelerations, in the same way as velocities;

• the distribution of mechanical stresses in the two bodies during the collision, which allows the calculation of the maximum impact force.

The simulations can be performed immediately, by modifying the input data, the program offering the data of interest, kinematic for the sports coach, regarding the performance and the mechanical tensions, for the sports doctor, regarding the injuries that can occur. Figures 1 and 2 show two sequences of the software graphics module, which show values with input data and impact velocities graphs, respectively.

In the same way you can see the graphs corresponding to the accelerations of the two athletes. If desired, activating the option of "finite element analysis", denoted "FEA", determines the distribution of equivalent mechanical stresses von Mises in the two generic bodies representing the two athletes.

Results and Discussion

A total of 52 rugby players took part in the experiment, grouped in pairs so that we had 26 teams. For each team, a video recording of the collision was made in the gym. Some of these records have been removed due to the fact that they did not guarantee a real collision. In the end, twenty recordings with real collisions resulted, which were processed.

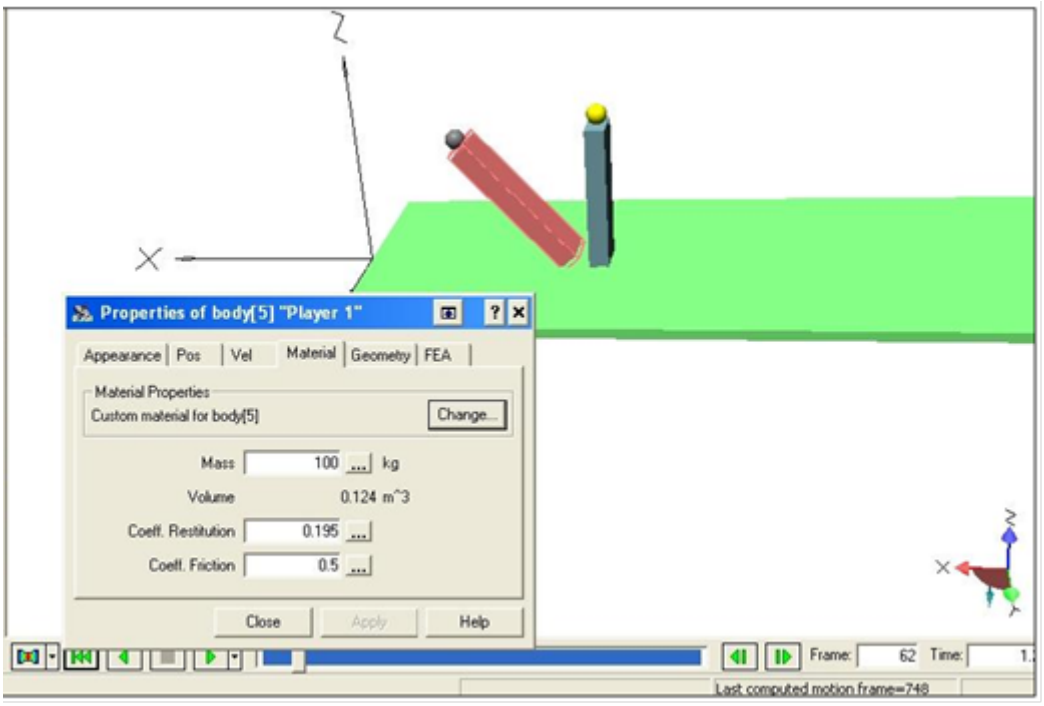

Figure 1. Sequence with input data

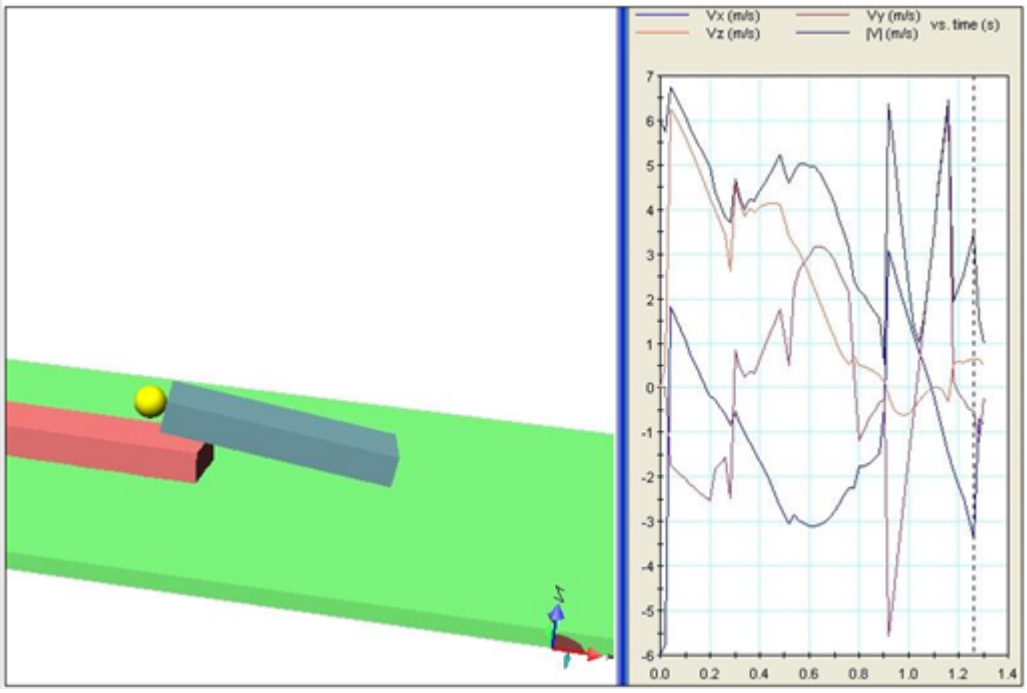

Figure 2. Sequence with kinematic analysis

For the experimental determination of velocities immediately before impact and immediately after impact, the videographic method was used. The video recordings were fragmented into sequences and then each sequence was processed using specialized software (MicroImage). By determining the distance in pixels between two successive sequences of landmarks fixed on athletes, the velocitiess in pixel/second could be calculated. After the calibration performed, by which the [millimeter/pixel] transformation coefficient was calculated, the distances and velocities in the International System of units of measurement could be determined, respectively meters and meter/second.

In the Graphic Software Module (GSM), the values of the speeds before the collision were entered as input data, determined experimentally. For the calculation of velocities immediately after the collision,

Table 1

Collision velocities before and after impact

The number of the team	Experimental determination				GSM determination	
	v_1 [m/s]	v_2 [m/s]	u_1 [m/s]	u_2 [m/s]	v_2 [m/s]	u_2 [m/s]
1	10.241	8.439	1.260	1.610	8.442	1.607
2	12.067	7.229	1.317	2.253	7.233	2.264
3	9.682	13.487	2.335	1.562	13.547	1.577
4	13.636	6.121	1.470	2.895	6.060	2.941
5	6.820	12.697	2.549	1.422	12.891	1.353
6	13.440	10.721	1.668	2.202	10.767	2.192
7	10.231	11.531	1.824	1.496	11.554	1.566
8	12.921	8.762	1.311	2.201	8.776	2.124
9	13.700	10.397	1.335	1.958	10.434	1.976
10	7.881	10.980	1.946	1.328	11.020	1.330
11	13.322	8.649	1.371	2.301	8.656	2.290
12	13.020	8.212	1.400	2.296	8.215	2.347
13	11.459	10.332	0.955	1.169	10.325	1.178
14	13.881	6.995	1.343	2.509	7.021	2.708
15	12.163	10.334	0.841	1.201	10.354	1.196
16	12.980	5.328	1.344	2.901	5.331	2.874
17	13.010	6.121	1.411	2.770	6.125	2.761
18	12.991	10.495	1.644	2.123	10.500	2.133
19	6.448	11.211	2.052	1.132	11.221	1.121
20	12.769	8.691	1.301	2.113	8.661	2.107

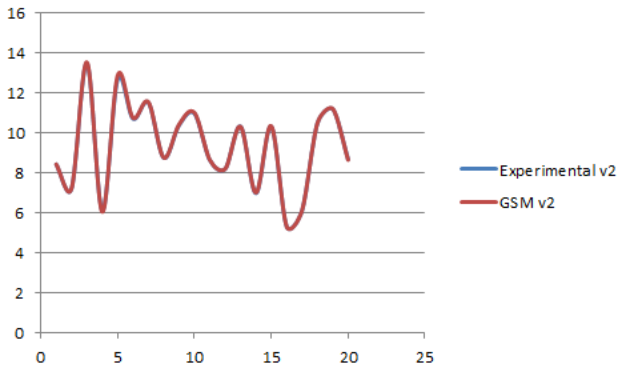

Figure 3. Velocities values v_2

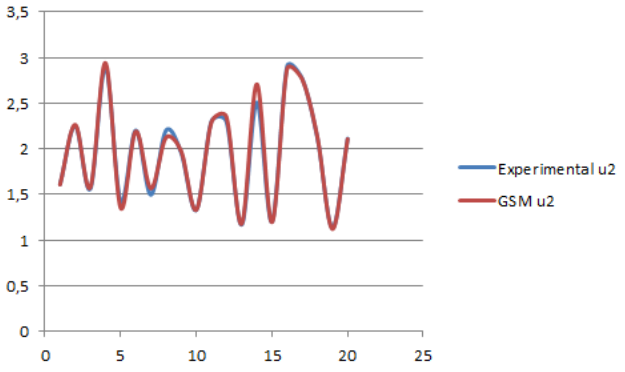

Figure 4. Velocities values u_2

the following mathematical relations were used in GSM [10; 11]:

$$v_2 = v_1 - \frac{(v_1 - u_1)(1+R)}{1+\frac{m_1}{m_2}}, \quad (1)$$

$$u_2 = u_1 + \frac{(v_1 - u_1)(1+R)}{1+\frac{m_2}{m_1}}, \quad (2)$$

where: m_1, m_2 – the masses of the colliding bodies;

v_1, u_1 – bodies velocities at the beginning of the impact;

v_2, u_2 – bodies velocities at the end of the impact;

R – restitution coefficient to collision.

Table 1 shows the values of the collision velocities determined experimentally and by GSM.

If the values for v_2 and u_2 obtained experimentally and with the help of GSM are analyzed, it is observed that they are within an admissible error limit. By plotting the graphs of these speeds depending on the collision team, it can be seen that the two graphs, experimental and GSM, are practically overlapping, so that the Graphic Software Module can be validated from this point of view.

Figures 3 and 4 show the variation graphs for v_2 and u_2, experimental and obtained with GSM. In the graphs, on the abscissa axis are the values representing each collision team and on the ordinate axis are the values of the corresponding velocities.

Large differences can occur when the necessary changes are not made to the coefficient of friction with the ground, when simulating special play situations, on wet ground, for example. In these cases, the value of the coefficient of friction must be modified according to the recommendations in the literature.

Conclusions

The Graphic Software Module can prove its usefulness in the theoretical preparation of matches, knowing that performance requires both physical training, as well as intellectual and mental training. Awareness of possible risks, the need to obtain certain parameters of motor skills, through training, to achieve performance and the "criterion of collision", visualization of possible situations by simulation, etc., all together can lead to adequate theoretical training to achieve performance.

Using the biomechanical analysis of the collision of two sportsmen, such as the case of two rugby players could be useful to a coach in defining the structure of a team.

The GSM could be used in Sports Medicine in order to evaluate and prevent possible accidents. In this case, the simulations using the calculated biomechanical parameters and the anthropological data of the sportsmen could eliminate unwanted situations causing accidents.

Mathematical modelling of the impact of two athletes can help a trainer in preparing the team for competition. Thus, on the basis of some video records of opposite team, the velocities developed during a game by the players of that team can be determined and then entered into GSM for analysis.

At the same time, knowing the value of the average percussion force, on the basis of impact duration approximation, the sport physician may specify if accident may occur or not. The best variants, both concerning the lesions and the performance, can be chosen.

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