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Experimental determination of the coefficient of restitution

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Abstract. The aim of this study is to make an experimental determination of restitution coefficient during the clash between ball and stick in oina game. This study is made using a complex system for movement analysis named VICON, on 17 oina balls, that have different wear stages, in contact with two different sticks that have different texture. We make the measurement of cinematic parameters of specific points that are marked, on the equipment, during movement. These parameters are used for calculate, using 2 methods, the restitutions coefficients. The values of these coefficient are 0.44-0.545. This analysis allows to make a prediction of balls trajectory, based on movement measurement during clash and also help to optimization of motor performance in oina game.

1. Introduction
The behaviour of the specific equipment in sports activities could influences the sports performance and results, and this is also presenting in oina game [1].

The performance in oina game is the result of the shot stick, that could be optimized by laboratory research.

In laboratory, using the movement analysis of stick shooting, could be determinate the kinematic parameters of the person and of the stick [1].

For make the transfer of these parameters to oina ball and make a prediction of trajectory, we propose in this study, to determinate the coefficient of restitution (CR) during the clash between stick and oina ball [2].

Start from the definition, the coefficient of restitution (CR), is specific for clash and it is the ratio between two percussions. The percussion is the variation of the object impulse during clash, this means that CR is the ration of relative speeds, before and after clash between two objects $CR = v2/v1$.

Experimental way for evaluate and calculate CR could be use by analyse the clash (free fall) between a sphere and a fix surface, that could be consider to have infinite weight and speed zero [3].

Start from this aspect we determinate the CR between ball and stick, like radically of the ratio between height H $_2$ of ball after clash, and height H $_1$ of ball before clash ($CR = \sqrt{H2}/\sqrt{H1}$).

2. Material and methods
The measurement of the oina balls movement was made by the Laboratory of Innovative Processes and Techniques in Bioengineering from the Research Infrastructure in Applied Sciences – INCESA (http://www.incesa.ro/#/), from the University of Craiova with a complex system of capture and image processing called VICON (http://www.vicon.com) of the INCESA Laboratory (Figure 1). This system records the movement of the balls with14 high-speed cameras (Figure 2).

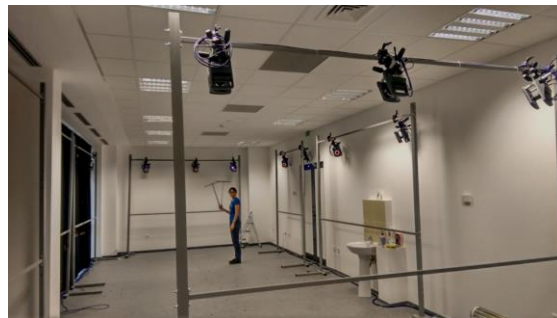**Figure 1.** Position of the 14 cameras inside the Laboratory of Innovative Techniques and Processes in Bioengineering.

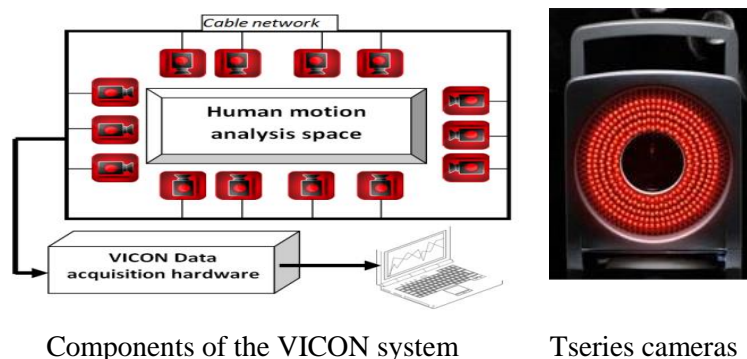Components of the VICON system   Tseries cameras

Figure 2. Diagram of the VICON system.

All the 14 cameras are synchronized by a synchronizer. Before starting the measurements, the working space must have certain reference points which are set with the help of fixed led lights arranged in the shape of a cross.

We select 17 oina balls: 3 of them are for the first time use and 14 from them are used before,3 balls from the second lot have been used by girls team and have small weights (around 100 g), and 11 balls have been used by boys team.

The balls are leader cover and inside have horse hair. 15 balls are approved by Romanian Federation of oina (FRO), and 2 of them are not, yet, approved by FRO. The ball has different wear degreases, that allow us to make 4 groups of the balls (0-new, 1- used,2- used,3- very used ball), depend on the number of the games that involved these balls (Figure 3).

0 (new ball)   1 used ball   2 used ball   3 very used ball

Figure 3. The 4 groups of the balls (0-new, 1,2,3very used ball), with different wear degreases.

Figure 4. The oina balls (new and used) with 4 markers.

In Table 1 we present the dimensional characteristics. Because the balls surface is not perfect, we propose to take in consideration the arithmetic average of the diameter, that is the result of 3 diameters (measured in 3 rectangular plans) [4]. We use for make the measurement the vernier that is part of VICON system.

We use an electronic scale for measure the balls weight and the accuracy is 1g (Table 1).

We note the balls form 0 to16-th, and we put 4 markers on 4 points (each marker has 6 mm diameter and 0.5g) (Figure 4).

Table 1. Dimensional characteristics of the balls and wear degreases.

Ball number	diameter1 [mm]	diameter2 [mm]	diameter3 [mm]	Medium diameter [mm]	weight [g]	Waste degree
0	76	74	73	74.3	123	0
1	72	75	72	73.0	100	1
2	72	73	75	73.3	121	2
3	74	75	72	73.7	119	2
4	74	75	76	75.0	138	3
5	74	74	73	73.7	179	2
6	71	72	70	71.0	121	2
7	73	73	74	73.3	138	2
8	74	74	77	75.0	140	2
9	73	75	74	74.0	118	3
10	75	76	75	75.3	98	2
11	73	74	75	74.0	105	1
12	75	75	74	74.7	124	1
13	74	76	74	74.7	123	1
14	74	73	73	73.3	102	1
15	72	69	68	69.7	138	0
16	74	75	74	74.3	122	0
Average values of the 17 oina balls				**73.7**	**124.05**	

The stick is specific for oina game and has 1m length. We use two sticks made of acacia (stick 1) wood and beech wood (stick 2).

The diameters in the clash point are around 44mm for stick 1 and 46mm for stick 2.

The system that we use for make the experiment is presented in Figure 5.

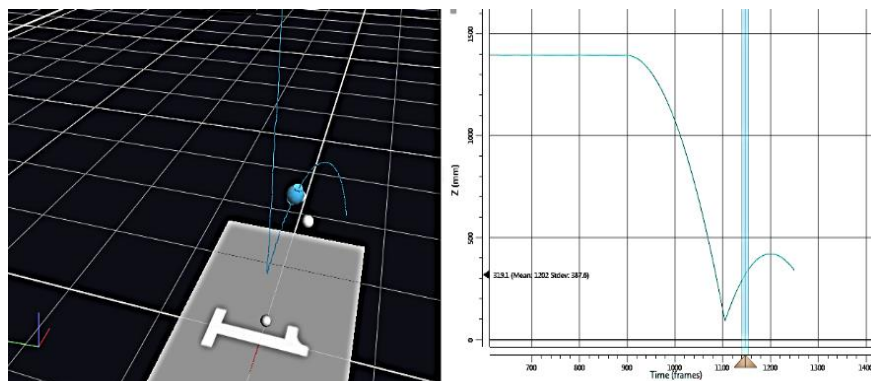**Figure 5.** The oina ball with 4 markers suspended by vacuum pump.

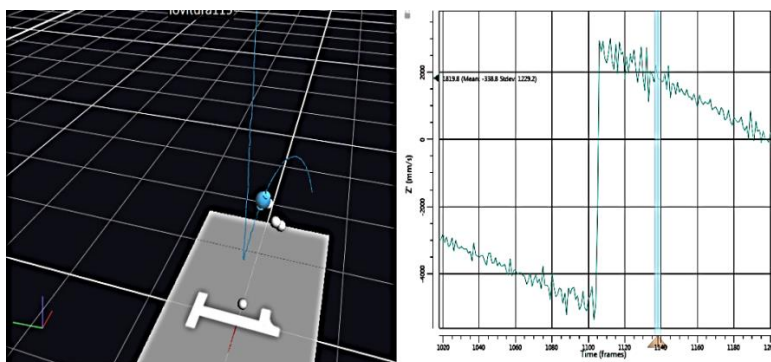**Figure 6.** The oina ball trajectory in free fall.

Figure 7. The variation of the velocity of oina ball in clash moment – small scale.

It has a vacuum pump with small power which is suspended on a beam at an adjustable height.

We make video recordings from the moment of the fall start from vacuum system, at 2 different heights (1000 mm and 1400 mm). Each ball has free fall 3 times. The stick is fixed on the floor using two systems for grip.

Using the VICON system, 400Hz frequency, we record the ball movement during free fall, during the clash and the trajectories after clash.

NEXUS software which the VICON associated, we obtain the maxim heights values of fall and lifting, after clash. The accuracy of the measurement is under 1 mm (Figure 6).

The NEXUS soft, by numerical derivation, calculate the ball speed before and after clash between ball and stick (Figure 7).

These parameters have been used for calculate the coefficient of restitution.

3. Results and discussion

We calculate CR using two methods [5]: ratio between heights up and fall of the ball ($CR = \sqrt{H2}/\sqrt{H1}$) and the second method is ratio between velocity after and before the clash ($CR = v2/v1$).

These parameters have been recorded by video cameras and analysed by Nexus software. For high accuracy the scale for read the velocity was large (Figure 8).
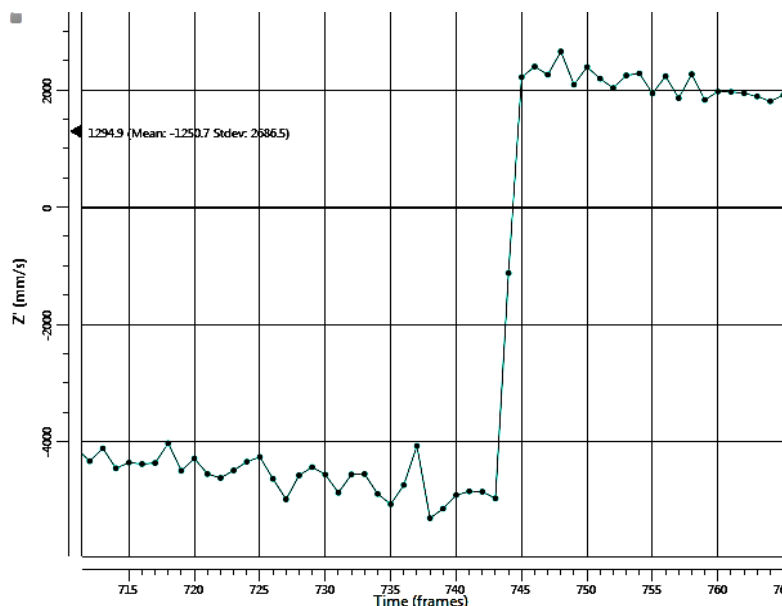

Figure 8. The variation of the velocity of oina ball in clash moment – large scale.

We make the measurements of heights and velocity for fall and up after the clash for 17 balls during the clash using two sticks:
- the beech stick that was made from wood boiled and dry before processing (approved by FRO);
- acacia stick that was made from wood which is dry before processing (not approved by FRO).

We used a specific equipment using vacuum pump and the balls fall down from 1000mm and from 1400mm [6, 7]. We made more than 200 measurements.

The values of CR are presented in table 2.
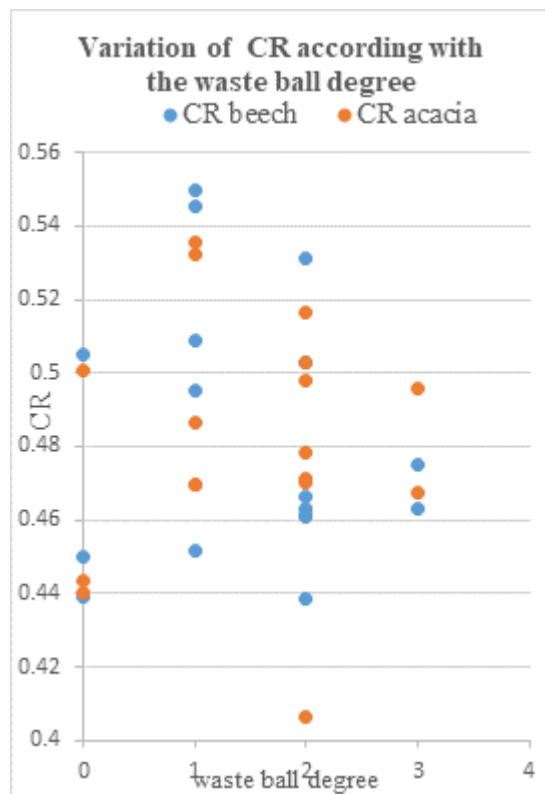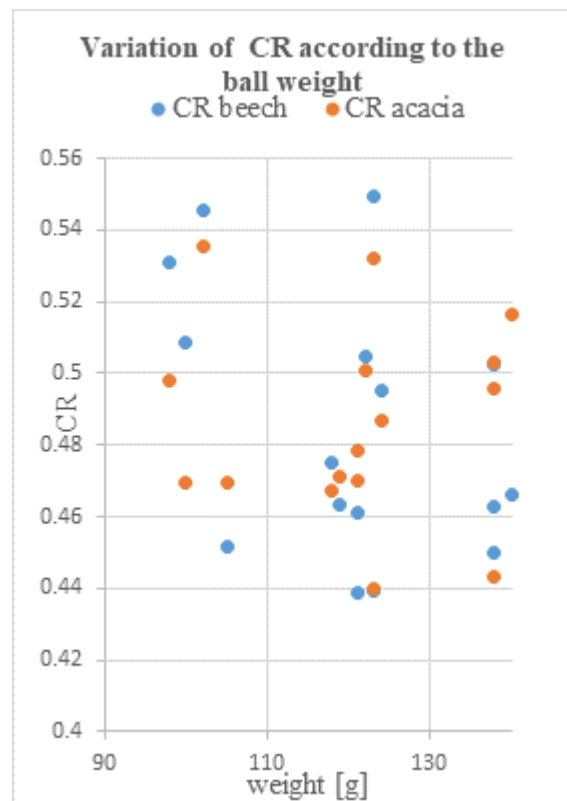
Data analysis show:
- beech stick is faster than acacia stick, only for news balls and a little bit waste;

CR is reversal proportional with ball weight, the lighter the balls the more coefficient of restitution (CR) which specific for clash, is more (Figure 9);
- the new balls (number 0,15,16) has CR less than the waste balls (Figure 10);
- the balls that have a small waste degree (degree 1) have a CR between 0.451-0545 (Figure 9);
- the balls that have a high waste degree (degree 2) and very used balls (degree 3), have a decrease of CR, but the medium values of CR are 0.477-0.482 (Figure 9);

Table 2. The averages values of coefficient of restitution (CR).

Ball number	CR acacia	CR beech	Waste degree
0	0.440115	0.439128	0
1	0.469594	0.508702	1
2	0.469882	0.438675	2
3	0.471334	0.463233	2
4	0.495761	0.463094	3
5	0.406500	0.461169	2
6	0.478417	0.461092	2
7	0.503082	0.502780	2
8	0.516696	0.466263	2
9	0.467406	0.475211	3
10	0.498060	0.530934	2
11	0.469763	0.451841	1
12	0.486595	0.495065	1
13	0.532254	0.549674	1
14	0.535353	0.545605	1
15	0.443389	0.450128	0
16	0.500623	0.504781	0

Figure 9. Variation of CR according with weight ball.

Figure 10. Variation of CR according with waste ball degree.

4. Conclusions

This study could be a propose for FRO regarding change the rule of oina game (which was approved in 2004), like:

   - the stick must to be by beech wood (because of weight difference generated by processing degree of the wood, beech stick is also more manoeuvrable);

   - the balls must have a CR between 0.48 and 0.50 [8, 9, 10].

   For maintain the CR during the oina game, the ball has not to be new, not very waste (no more the waste degree 1). For this reason, we propose to FRO an equipment for evaluate the real waste degree of the ball, that is used for game. This is the check equipment for the ball.

5. References

[1]   McGinnis P M 2005 *Biomechanics of sport and exercise 2nd ed.* (Champaign: IL) p 85

[2]   Persson J 2012 *Phy.Ed.***11** 662-3

[3]   Haron A and Ismail K A 2012 *IOP Conf. Ser.: Mater.Sci.Eng.* **36** 012038

[4]   Kagan D and Atkinson D 2004*Phy.Teacher* **42** 89-92

[5]   Briggs L 1945 *Nat. Bur.Standard Research Paper RP1624* **34** 1-24

[6]   Dong H and Moys M H 2006*Powder Tech.***161** 22 – 31

[7]   Muller P and Poschel T 2011 *American Phy.Soc.Phy.Review* **E 84** 0213021

[8]   Wallace C 2008 *Coefficient of Restitution: A Comparison of Major League and Little League Baseballs* (California State: Project J1935 Science Fair)

[9]   Mohazzabi P 2011 *The Phy. Teacher.* **49** 89–90

[10]   Arakawa K 2014*Applied Mech.Mater.Trans Tech Pub.Switzerland* **566** 443-8

[11]   Weir G and McGavin P 2008 *Phy.and Eng. Sci.* **464** 1295–307