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Building a basketball shooting model based on neural networks and a genetic algorithm

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ABSTRACT: A neural network is a mathematical model of information processing that simulates a biological neural network. An artificial neural network consists of a large number of neurons with simple functionality and topological structure to form a parallel processing computational structure. Newton's second law of motion posits: given an external force, the acceleration of an object is directly proportional to the resultant external force and inversely proportional to its mass. The direction of acceleration and that of the resultant external force are the same. In this article Newton's law of motion is used to systematically and scientifically research the motion of the shooting of basketballs to guide the development of genetic algorithms and to assist the training of basketball players. The results show that the basketball model, using the law of motion, is conductive to improving the hit ratio of players.

INTRODUCTION

All higher education institutions (HEI) engaged in engineering education need to review existing courses to take account of globalisation [1]. Engineering education research represents a unique component of education and research. Research in engineering education emphasises not only research and discovery, but also implementation [2]. Engineering education research should be characterised by a unique interdisciplinary approach with engineering education researchers from various backgrounds in engineering, science, social sciences and educational psychology investigating engineering education [3]. Contemporary research in engineering education focuses not only on the learning processes and individual versus team learning, but also on the educational techniques used in the classroom setting [4].

Newton's laws of motion were put forward in the *Philosophiae Naturalis Principia Mathematica* in 1687 [5]. Newton's second law of motion says that when subject to an external force, the acceleration of an object is directly proportional to the resultant external force and inversely proportional to its mass. The direction of acceleration and that of the resultant external force are the same [6]. Shooting is the core skill in basketball, so developing the correct shooting method to improve the hit ratio is the key to winning the game [7]. In traditional basketball training, the players exercise extensively to adjust their shooting method by increasing their experience and, hence, improving their hit ratio. Effectively, they are exploring Newton's law of motion [8]. This method not only wastes time and effort, but does not achieve good results [9].

Newton's laws of motion applied to projectiles in oblique motion are used in this article to research basketball motion. During the research, the mathematical relation between trajectory, shooting height, shooting angle, and shooting angle for success was developed. An analogue simulation method was adopted. The experiment produced a guide for shooting training and the correctness of the conclusions was verified.

1. Based on mathematical analysis, MATLAB software was used for an analogue simulation. The various situations encountered in basketball were compiled and analogue simulation programs were produced. The state of a basketball game was captured under various conditions; hence, providing a correct data reference.
2. MATLAB software was used for a simulation and an artificial network model was used to predict the development of the hit ratio of players.

NEWTON'S SECOND LAW

Newton's second law of motion states that under an external force, the acceleration of the object, a, is directly proportional to the resultant external force, F, and inversely proportional to its mass, m [10]. The direction of acceleration and that of the resultant external force are the same, see Equation (1):

$$F = ma \qquad (1)$$

The following conclusions may be drawn:

1. The object is accelerated only by an external force, and the direction of acceleration and that of the resultant external force are the same. If the resultant external force is unchanged, the acceleration is also unchanged. If the resultant external force changes, the acceleration will also change.
2. Newton's second law is an instantaneous law. Force and acceleration are simultaneous. When the external force disappears, the acceleration also disappears and the object will then remain in motion under inertial effects, i.e. according to Newton's first law of motion.
3. Equation (1) is a vector equation. The positive direction should be defined and a positive value results, if the direction of force or acceleration is in the positive direction, otherwise, the direction will be the negative. Generally, the direction of acceleration is taken as the negative direction.
4. The force can be decomposed into orthogonal components in two perpendicular directions, see Equation (2).

$$\begin{aligned} F_x &= ma_x, \\ F_y &= ma_y \end{aligned} \qquad (2)$$

EXPERIMENTAL METHOD

The motion of a basketball under ideal conditions was mathematically analysed and the motion simulated. The correctness of the conclusion was verified by experiment. Ten male and 10 female basketball players were selected.

Table 1: Basic information about the experimental subjects.

Number of people	Sex	Average age	Height (cm)	Weight (kg)
10	Male	25.4	186.3 ± 9.1	87.8 ± 10.9
10	Female	24.2	179.4 ± 8.8	69.1 ± 7.7

Specialised shooting training was provided for the subjects for 12 weeks to determine the improvement in hit ratio and how it accorded with the mathematical derivation. The specific plan was as follows:

1. The specialised sport training was from October 2012 to December 2012, for 12 weeks.
2. From Monday to Friday, the subjects would participate in training from 16:30 to 17:30 and conduct shooting training under the guidance of professional coaches and according to conclusions obtained from the mathematical derivation.
3. Feedback was provided on a weekly cycle.
4. Every subject was asked to become familiar with the research, including method, motion requirements and test process. Also, they were asked to keep a regular diet and to rest during the experiment and to maintain a good mental state.

FORMULA DERIVATION AND DATA PROCESSING

Formula Derivation of Motion Curve of Basketball and Simulation

Not considering the size of basketball and hoop, the basketball is regarded as a projectile of point mass at the centre of the ball in oblique motion. The origin of co-ordinates is fixed at the ball's centre and the equations of motion in x (horizontal) and y (vertical) direction are shown in Equation (3). The trajectory of the ball's centre can be obtained as shown in Equation (4) [11]:

$$\begin{aligned} x(\mathrm{t}) &= \mathrm{v} \cdot \cos\theta t \\ \mathrm{y}(\mathrm{t}) &= \mathrm{v} \cdot \sin\theta t - \frac{1}{2} g t^2 \end{aligned} \qquad (3)$$

$$y = x\tan\theta - x^2 \frac{g}{2v^2\cos^2\theta} \qquad (4)$$

The condition of a ball's centre hitting the hoop can be expressed as a relation between shooting angle, shooting velocity, shooting height, incident angle and shooting angle of the hoop. Then, the corresponding shooting angle and incident angle can be calculated according to different shooting velocities and shooting heights.

Given a velocity v = 10 m/s and shooting angle $\theta = 60^{\circ}$ and using MATLAB software for an analogue simulation, the trajectory of a basketball in the x and y directions in 0 to1 seconds is shown as Table 2.

Table 2: Trajectory of a basketball in x, y direction.

	Time (s)										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
X(m)	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Y(m)	0	0.81	1.53	2.14	2.66	3.08	3.39	3.61	3.72	3.74	3.66

Formula for the Minimum Shooting Velocity and its Simulation

For the shooting height h, to get the basketball into the hoop under this height, the minimum shooting velocity is:

$$v_{\min}=\{g[H\text{-}h+\sqrt{L^2+(H\text{-}h)^2}\,]\}^{\frac{1}{2}} \tag{5}$$

MATLAB software was used for an analogue simulation to determine the relation between minimum shooting velocity and shooting height when the players shoot the basketball from the free throw line, as shown in Table 3.

Table 3: Relation of minimum shooting velocity and shooting height, when shooting from the free throw line.

Shooting height (m)	1.7	1.72	1.74	1.76	2.94	2.96	2.98	3.00
Minimum shooting velocity (m/s)	7.53	7.51	7.50	7.48	6.52	7.88	6.49	6.47

MATLAB software was used for an analogue simulation to determine the relation between minimum shooting velocity and shooting height, when the players shoot the basketball from the three point line, as shown in Table 4.

Table 4: Relation of minimum shooting velocity and shooting height, when shooting from the three point line.

Shooting height (m)	1.7	1.72	1.74	1.76	2.94	2.96	2.98	3.00
Minimum shooting velocity (m/s)	8.71	8.70	8.68	8.67	7.90	7.88	7.87	7.85

The data in Table 3 and Table 4 show that:

1. When the shooting height is between 1.7 - 3 m, the minimum shooting velocity is between 6.47 - 7.53 m/s through calculations when shooting at the free throw line. Therefore, specific exercises can be conducted for players to make them improve their hit ratio from the free throw line.
2. In case of shooting at three point line, the minimum shooting velocity is between 7.85 - 8.71 m/s. Therefore, specific exercises can be conducted for players to improve their hit ratio from the three point line.
3. Whether near the free throw line or near the three point line, the minimum shooting velocity and shooting height approximately satisfy a linear relation; the minimum shooting velocity decreases with the increase of shooting height of players. Besides which, it can be seen that players of low shooting height should increase their shooting force when the shooting distance increases, to ensure an effective hit ratio.
4. The formula for the incident angle of shooting is:

$$\tan\psi=\tan\theta\text{-}\frac{2(H\text{-}h)}{L} \tag{6}$$

MATLAB software was used for an analogue simulation of the shooting angle near the free throw line for different shooting heights and shooting angles, as shown in Table 5. It can be seen that the shooting angle is related to the shooting angle θ and shooting height h.

Table 5: Shooting angle near free throw line for different shooting heights and angles.

Shooting height (m)	Shooting angle (°)							
	20	25	30	35	40	45	50	55
1.7	-15.3	-10.3	-4.8	5.0	11.5	19.3	28.2	38.1
1.71	-15.1	-10.1	-4.5	5.2	11.7	19.5	28.4	38.3
1.72	-14.8	-9.8	-4.3	5.4	11.9	19.7	28.6	38.5
1.73	-14.6	-9.5	-4.0	5.6	12.1	19.9	28.8	38.7
2.97	18.0	22.6	27.3	35.6	38.4	43.5	48.8	53.7
2.98	18.3	22.9	27.5	35.8	38.6	43.7	49.0	53.9
2.99	18.5	23.1	27.7	36.0	38.8	43.9	49.2	54.1
3.00	18.7	23.2	27.9	36.2	29.0	44.1	49.4	54.3

The shooting angle near the three point line for different shooting heights and shooting angles is presented in Table 6.

Table 6: Shooting angle near three point line under different shooting height and angle.

Shooting height (m)	Shooting angle (^{o})							
	20	25	30	35	40	45	50	55
1.7	-15.1	-11.2	-5.1	6.0	12.3	19.8	29.3	39.3
1.71	-15.0	-11.1	-5.2	6.2	12.4	19.9	29.4	39.4
1.72	-14.9	-11.0	-5.3	6.4	12.5	20.0	29.5	39.5
1.73	-14.8	-10.9	-5.4	6.6	12.6	20.1	29.6	39.6
2.97	19.1	23.1	28.1	36.3	39.5	44.7	49.3	54.4
2.98	19.2	23.2	28.2	36.4	39.6	44.8	49.4	54.5
2.99	19.3	23.3	28.3	36.5	39.7	44.9	49.5	54.6
3.00	19.4	23.4	28.4	36.6	29.8	45.0	49.6	54.7

The data in Table 5 and Table 6 show that:

1. The shooting angle changes with the shooting height and shooting angle. The best shooting angle decreases with the increase of shooting height. Therefore, shorter players should increase the shooting angle to increase the hit ratio.
2. Under certain shooting height, the best shooting angle changes obviously with the shooting angle.
3. Under certain shooting height, the shooting angle decreases with the increase of shooting distance and *vice versa*. Therefore, the shooting angle should decrease with the increase of shooting distance and *vice versa*.
4. With the increase of shooting height between 2.6 - 3 m, the best shooting angle for different heights almost tends to a constant value, indicating that when the shooting height of players is 2.6 - 3 m, the shooting angle for different distances is almost the same. This is convenient to players for fixing their shooting angle during training, as it enables players to highly co-ordinate the shooting action and shooting angle. This is beneficial in improving the hit ratio from different distances. It can be seen that the shooting height is also an important reference standard for selection of players.

Conclusion and Verification by Experiment

After detailed analysis of the motion of basketballs under ideal conditions, an experiment was carried out to verify the conclusions about improving the hit ratio of players.

After one cycle of exercise, a shooting test was conducted to gather statistics on the hit ratio of players. The shooting hit ratio of experimental subjects near the free throw line within the first six cycles is shown in Table 7 and Table 8.

Table 7: Statistics of the shooting hit ratio of male basketball players at free throw line within the first six cycles.

	Before experiment	Cycle					
		1	2	3	4	5	6
Hit ratio (%)	62.1	62.6	62.9	63.4	64.0	64.5	65.1

Table 8: Statistics of the shooting hit ratio of female basketball players at free throw line within the first six cycles.

	Before experiment	Cycle					
		1	2	3	4	5	6
Hit ratio (%)	59.7	60.2	60.6	61.1	61.5	62.1	62.6

The following conclusions are drawn from the data in Table 7 and Table 8:

1. Within the first six cycles, the shooting hit ratio (hollow basketball ratio) of male and female players at the free throw line improved continuously, indicating that the shooting training under guidance by theory is useful in improving the shooting hit ratio of players.
2. The improvement of hit ratio of male and female players at the free throw line after each cycle is almost the same, indicating that the effect has little relationship to the sex of the player in improving the shooting hit ratio of players at the free throw line.

The shooting hit ratio of experimental subjects at the three point line within the first six cycles is shown as Table 9 and Table 10.

Table 9: Statistics of the shooting hit ratio of male basketball players at the three point line within the first six cycles.

	Before experiment	Cycle					
		1	2	3	4	5	6
Hit ratio (%)	57.8	58.3	58.9	59.3	59.8	60.2	60.7

Table 10: Statistics of the shooting hit ratio of female basketball players at the three point line within the first six cycles.

	Before experiment	Cycle					
		1	2	3	4	5	6
Hit ratio (%)	55.6	56.2	56.7	57.3	57.9	58.5	59.0

It can be seen from Tables 9 and 10 that:

1. Within the first six cycles, the shooting hit ratio (hollow basketball ratio) of male and female players at the three point line improved continuously with male players, improving from 57.8% to 60.7% and female players, improving from 55.6% to 59.0%, indicating that the shooting training guided by theory is useful in improving the shooting hit ratio of players.
2. The improvement of hit ratio of male and female players at three point line after each cycle is almost the same, indicating that the effect has little relationship to the sex in improving the shooting hit ratio of players at the three point line.

Simulation of Artificial Neural Network Model

A Back Propagation (BP) neural network and a genetic algorithm were used for an analogue simulation. Taking the shooting status of the experimental subjects as the input to the neural network and using the data in Tables 7–10 as sample data, the shooting hit ratio of research subjects was predicted after the seventh cycle.

$$a = f(\sum_{i}^{\Re} WiPi - \theta) \tag{7}$$

$$net_{i,k} = \sum_{j=1} W_{i,j,k} O_{j,k-1} - \theta_{i,k}$$
$$O_{j,k} = f(net_{i,k}) \tag{8}$$

The frequently applied response functions include:

$$\sigma(s)=\begin{cases} 1 & s \geq 0 \\ 0 & s < 0 \end{cases} \tag{9}$$

$$y=\sigma(s)=s \tag{10}$$

$$\sigma(s) = \frac{1}{1+e^{-s}}$$
$$\sigma(s) = \tanh(\beta s) \tag{11}$$

The learning rate of the BP neural network was set at 0.9, the maximum error of the samples was 0.01 and the maximum cycle index was 1,000.

The input node number in the genetic algorithm was set at four (4); the intermediate node number was three (3); the output node number was one (1); the population size was 100; the crossover probability was 0.80; the mutation probability was 0.05 and the maximum evolution algebra was 1,000.

The BP neural network and genetic algorithm predictions are shown in Tables 11-14.

Table 11: Prediction results of the hit ratio of male players at the free throw line by artificial neural network.

Hit ratio	After 6th cycle	After 7th cycle	After 8th cycle	After 9th cycle	After 10th cycle
Actual value	65.1	65.5	65.9	66.4	66.9
BP predicted value	63.4	63.8	64.2	64.7	65.1
Predicted value by genetic algorithm	64.3	64.7	65.2	65.7	66.0

Table 12: Prediction results of the hit ratio of female players at the free throw line by artificial neural network.

Hit ratio	After 6th cycle	After 7th cycle	After 8th cycle	After 9th cycle	After 10th cycle
Actual value	62.6	63.0	63.4	63.9	64.4
BP predicted value	60.4	60.8	61.3	61.6	62.2
Predicted value by genetic algorithm	61.8	62.3	62.8	63.2	63.8

Table 13: Prediction results of the hit ratio of male players at the three point line by artificial neural network.

Hit ratio	After 6th cycle	After 7th cycle	After 8th cycle	After 9th cycle	After 10th cycle
Actual value	60.7	61.2	61.8	62.4	62.8
BP predicted value	57.6	57.9	58.4	58.9	59.5
Predicted value by genetic algorithm	58.7	59.3	59.8	60.4	61.0

Table 14: Prediction results of the hit ratio of female players at the three point line by artificial neural network.

Hit ratio	After 6th cycle	After 7th cycle	After 8th cycle	After 9th cycle	After 10th cycle
Actual value	59.0	59.5	60.2	60.6	61.2
BP predicted value	57.1	57.5	57.9	58.2	58.7
Predicted value by genetic algorithm	58.3	58.9	59.4	59.9	60.3

It can be seen from the data in tables 11-14 that the shooting hit ratio of male and female basketball players at the free throw line and three point line improved continuously with cycle and by the same amount, indicating that the theoretical experimental results are useful in improving the shooting hit ratio of basketball players.

CONCLUSION

Using Newton's laws of motion and by using an oblique model of projectile motion, the basketball motion under ideal conditions was researched. The relation between shooting motion curve, shooting height, and shooting angle was researched by using a mathematical model, experimental methods and simulations; the results were experimentally verified. The shooting hit ratio is improved by shooting training guided by the conclusions, indicating that the experimental conclusions are reasonable and effective.

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REFERENCES

1. Fromm, E.G. and R.G., Quinn, An experiment to enhance the educational experience of engineering students. *Engng. Educ.*, 79, **3**, 424-429 (1989).
2. Yeomans, S.R and Atrens, A., A methodology for discipline-specific curriculum development. *Inter. J. of Engng. Educ.*, 17, **6**, 518-524 (2001).
3. Parashar, A.K. and Parashar, R., Innovations and curriculum development for engineering education and research in India. *Procedia - Social and Behavioral Sciences*, 56, **1**, 685-690 (2012).
4. Parhami, B., Computer science and engineering education in a developing country: the case of Iran. *Educ. and Computing*, 2, **4**, 231-242 (1986).
5. Kuo, C-F.J. and Lin, S-C., Discretization and computer simulation of a rotating Euler-Bernoulli beam. *Mathematics and Computers in Simulation*, 52, **2**, 121-135 (2000).
6. Chauhan, N., Ravi, V. and Chandra, D.K., Differential evolution trained wavelet neural networks: application to bankruptcy prediction in banks. *Expert Systems with Applications*. 36, **5**, 7659-7665 (2009).
7. Forsythe, A.B., Freed, J.R. and Frey, H.S., Programmed Instruction Nucleus (PIN): a simplified author-language for computer-aided instruction. *Computers in Biology and Medicine*, 5, **6**, 77-88 (1975).
8. Cantwell, J.D., The physician who invented basketball. *The American J. of Cardiology*, 93, **4**, 1075-1077 (2004).
9. Yang, S., Li, C. and Xia, D., The modeling and simulation of a new cooperative driving lattice model of traffic flow with the consideration of forecasting effect. *J. of Convergence Infor. Technol.*, 7, **6**, 129-136 (2012).
10. Bao, X., Research on quick sort methods based on ID3 algorithm. *Modern Electronic Technique*, 27, **4**, 84-85 (2004).
11. Okubo, H. and Hubbard, M., Identification of basketball parameters for a simulation model. *Procedia Engng.*, 2, **2**, 3281-3286 (2010).