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A Study on Tennis Competition Enhancement Technology on the Basis of Virtual Reality Technology

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Abstract

With the development of the science and technology, as one of the hot direction of IT, the virtual reality technology has been widely used in more and more fields. Wherein, in sports competition, it is particularly prominent. This paper is based on the related theories of virtual reality, sets up the tennis dynamics model, using ODE technology to operate the simulation system. By simulating the trajectory and collision detection, this paper has drawn a conclusion that virtual reality technology can make accurate and scientific simulation on sports competition both in static and simulation lab environment. Therefore, the computer virtual technology has a catalytic effect on sports competition enhancement technology. Moreover, this paper will open up new ideas for the application of computer virtual technology on sports competition enhancement technology, and also provide the theoretical basis for related researches.

Keywords*: Virtual Reality Technology; Sports Competition; Tennis Dynamics Model; OED Technology; Simulation System*

1. Introduction

The evolution of virtual reality technology can be divided into the following four stages: sound-shape dynamic simulation (before 1963); virtual reality bud (1963-1972);putting forward the concept of virtual reality and the preliminary formation of corresponding theories (1973-1989); the further improvement and application of virtual reality theory (1990- present) [1].

The concept of virtual reality was firstly proposed by the founder of an US company -VPL Jaron Lanier. After that, virtual reality system came into being and now it has gained great development. In the field of military aviation, the US DARPA has already set the SIMNET virtual combat system as a key research project since the 1980s, which plays an important role in the military exercise and can be used to make simulation on weight loss environment. Furthermore, the application of virtual reality technology has brought an unprecedented revolution on industrial production. The simulation system applied in industry is not a simple environment simulation design, but has the ability to truly guide industrial production. Currently, the industrial simulation system contains user services layer function, database data and industrial simulation experiment platform. This system can achieve the application of B/S and C/S architectures, seamlessly integrate with enterprises' ERP and MIS system, support the mainstream databases such as SqlServer and Oracle, and can also make virtual production (CAD), virtual design (CAM) and virtual assembly (CAE) [2].

In china, virtual reality technology developed late, and the National Development Plan as well as some key universities have set it as a key research project [3].

In China, study on VR technology has a later beginning.[3] University of Beijing Aeronautics and Astronautics is the first to study virtual reality technology, therefore it has the relatively mature technology. In recent years, with the further development of study, it has gained some achievements: developed certain hardware system in connection

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with VR visual interface, and proposed correlation algorithm on hardware applications; achieved network design of a distributed virtual simulation and so on. Tsinghua University carried out research on the presence of virtual reality; Zhejiang University developed the high-speed roaming algorithm based on virtual reality technology [4].

China has completed two “863” projects on virtual reality technology. Recently, China shifts the focus to the development of software and hardware of virtual reality dynamic simulation system, and has developed some products, such as: virtual reality editor, human physical simulation system, 3D simulation platform, industrial simulation system, and 3D simulation system development package, which have been widely used in many fields. [5] At present, China is studying on these several directions: dynamic environment modeling and simulation technology, 3D graphics in real time and display technology, virtual modeling of intelligent voice recognition technology and the application of large-scale distributed network of virtual reality technology, in which the research prospect of distributed network has great value. In the process of building the international space station, for member states are throughout the world, rebuilding simulation system in these countries is usually necessary, so as to arrange unified deployment. However, the distributed network can achieve this goal, which can greatly reduce research funding and save costs. So, research on virtual reality technology has a broad sense for the development of society.

2. Introduction about Related Application Technology

2.1. Virtual Reality Technology

Virtual reality (virtual environment) refers to a real-time simulation of the human perception of the world, whose abbreviation is VR. Virtual reality technology is made up by a variety of techniques, including computer technology, computer network technology, audio technology, multi-sensor technology and intelligent interface technology. It is the result of multi-discipline intersects. Users can interact and perceive through a variety of interactions, such as hearing, smelling, sight, touch and body movements. Currently, this technology has been widely used in medical, military simulation, remote control robot design and many other fields [6].

Domestic virtual reality engine has almost been mature, and several simulation software are already universal, such as VRP, EON Reality, patchwork3D and so on. Wherein, as the first domestic virtual reality application software which owns independent intellectual property rights, VPR has been widely used in many fields, like industrial simulation, computer simulation, competitive sports, and computer interaction and so on.

2.2. ODE Technology

ODE (Open Dynamic Engine) is developed by Russell Smith, and it is the open source dynamics engine wrote with C ++ language. It is widely used in the process of simulation experiments on rigid objects, for there is advanced joint coupling and collision detection system in the interior [7].

The fundamental goal to design ODE is to do real-time and interactive simulation experiments, which can simulate real scenarios fast and stably. Also ODE itself is extremely stable, and has prominent capability to prevent simulation errors. When building ODE simulation models, simulation world (for dynamic calculations) and space collision (for collision detection) are also necessary. Therefore, two models of the simulation object is required: respectively is dynamics model and geometry.

The simulation object established by ODE has the following features:

1) The corresponding coordinate of rigid body to centroid can be represented by vector 3x1:

$$p = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} \tag{1}$$

2) The position of rigid object can be represented by 3x3 matrix, then the relation between point a on the rigid body and the a’ in the global coordinate system can be showed like this:

$$a' = Ra + p \tag{2}$$

3) The line speed v of a certain point on rigid body can be represented by vector 3x1:

$$v = \begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \begin{bmatrix} dpx/dt \\ dpy/dt \\ dpz/dt \end{bmatrix} \tag{3}$$

4) The position of rigid body changes with time t, and it can be represented by vector 3x1:

$$\omega = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} \tag{4}$$

5) Features of Constant: centroid of rigid object, mass and inertia matrix.

2.3. Simulation System

Simulation system can be mainly classified into object-oriented simulation, multimedia simulation, visualization simulation, intelligent simulation, qualitative simulation, distributed interactive simulation and simulation based on VR. Compared with other forms, VR based simulation pays more attention to perception and interactive function. Because athletes almost rely on perception to compete, this paper adopts the simulation system based on VR.

Simulation system based on VR is a software used to assist analyzing, which adopts three-dimensional modeling and simulation methods to design appropriate motion simulation platform. [8] Three are four modules: simulation processing, input and output, three-dimensional modeling and computational analysis. The simulation processing module is the core part, which is of great importance in this study. Simulation processing module is mainly responsible for motion simulation, dynamics modeling, graphics rendering and collision detection. It integrates the graphics rendering engine and ODE (dynamics engine), and inputs this into the system, whereby achieving the simulation platform for visualization method. The main process is shown in Figure 1:

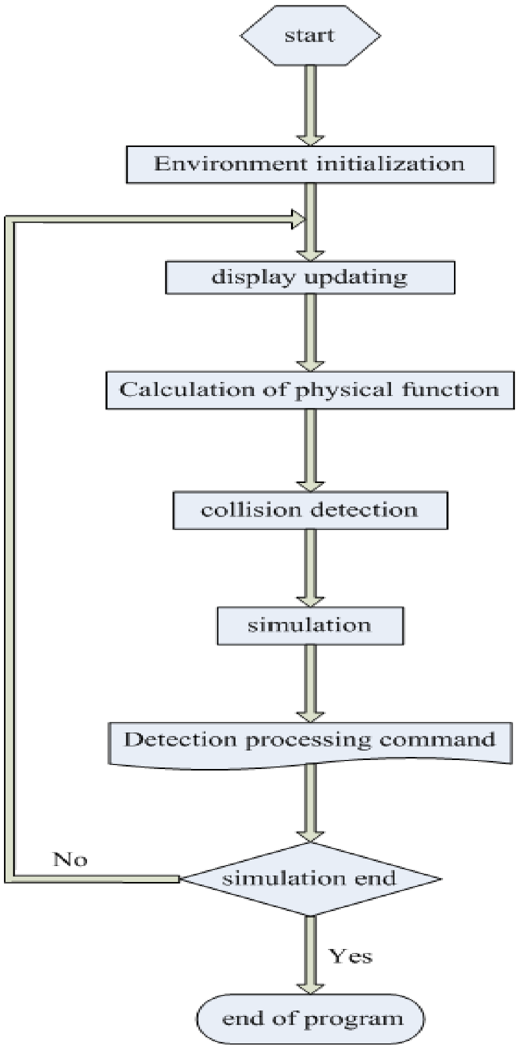

Figure 1. Process of Simulation

The simulation system for competitive sports based on VR mainly consists of three modules: input system, output system and Virtual Environment Generator. Among them, the input system completes the simulation processing, manages to collect the corresponding physical and sports information and imports the information into the virtual environment generator via the converter, make graphics rendering, establishes three-dimensional model and so on. After that, it will be imported into the output system via the signal converter to the output system, forming the visual simulation platform.

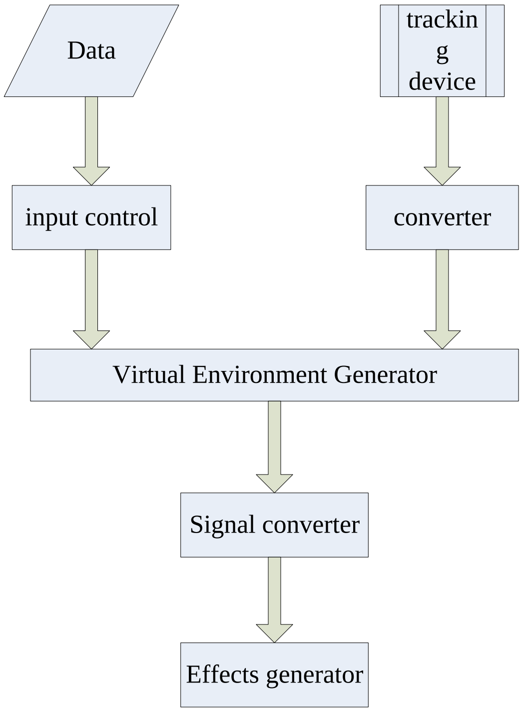

Figure 2. The Simulation Chart of Competitive Sports Based on VR

3. The Application of Sports Enhancement Technology Based on VR

3.1. Analysis on Applied Technology of VR Technology

VR technology has the features of dynamic interactive, multidimensional digitized and high immersion, and the relationship among them is shown in Figure 3, to pursue the emerging interactive media with human-computer interaction and various output forms. Because modern competitive sports gradually pursue the new pattern of high-level, high-difficulty, high-technology and precise training, modern scientific and technological means are widely used in daily physical training.

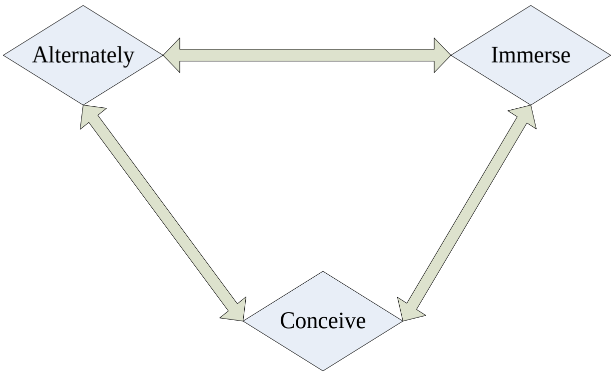

Figure 3. Three Basic Characteristics of VR Technology and the Diagram of their Relations

In early years, VR technology was applied in human animation, which experienced dynamic control, motion capture and kinematics control based on the controller and so on. The effect is very realistic if use sensors to record real human motions, forming three-dimensional virtual human, which is drove by the recorded data to complete the motion [9]

In recent years, VR technology has been applied to various sport competitions such as, virtual gymnastics training and large-scale group calisthenics. Virtual gymnastics system refers to establishing models for the true motions of gymnasts, so that the objects in virtual environment can accurately reproduce gymnastic movements, athletes can improve their own defects by observing the action in virtual environment, thus greatly improving the technique level.

Large-scale group calisthenics training system is similar thereto. The simulation system consists of three subsystems: 1) formation design system, which designs the corresponding actions in all links through simulation; 2) actions generation system, which designs actions according to the data of human movement in the system; 3) formation changes system, which integrates the formations and action designs of the virtual crowd in all links and then forms a continuously changing formation. Therefore, the time to design formation can be greatly saved, so that can improve the training efficiency. In addition, VR technology played an important role at the 2008 Olympic Games. When, simulation training were adopted in many projects that have advantages, like diving, trampoline, gymnastics, group calisthenics and so on, breaking the traditional training methods and achieving the major shift from human observation to high-precision capture analysis, which is helpful for enhancing the level of training.

3.2. Establishing Models

In the process of tennis motion, it will be affected by many factors, such as, air resistance, gravity and the Magnus force, it is showed in Figure 4:

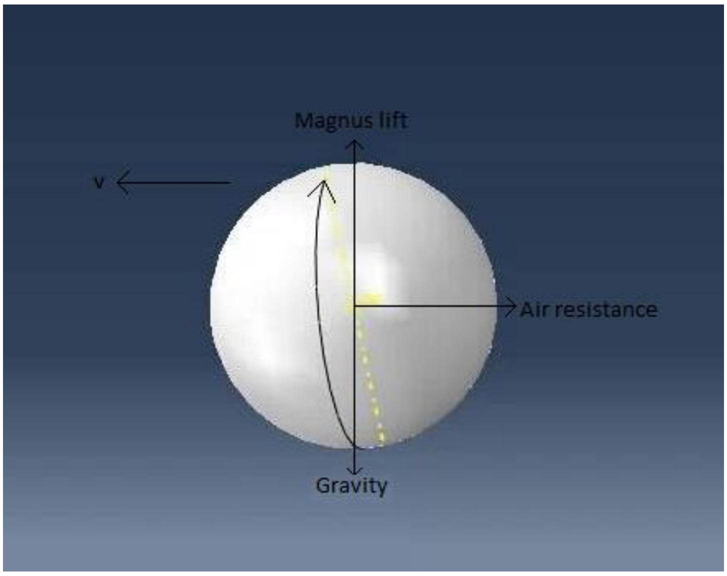

Figure 4. The Tennis Motion Force Diagram

In the above force, the air resistance is opposite to the actual movement direction of the ball, and its size is related with these factors such as, drag coefficient Cd, linear velocity v, the ball wind direction area A and air density ρ. It can be calculated and analyzed in accordance with the following formula:

$$Fd = \frac{1}{2} Cd\rho Av^2 \tag{5}$$

In this formula, Cd is measured through wind tunnel experiments. In this paper, it assumes that the spinning speed of the ball and translation speed Fm determine the value of Cd, then it can be calculated and analyzed according to the following formula:

$$Cd = 0.508 + \left(\frac{1}{22.053 + 4.196\left(\frac{v}{\omega}\right)^{5/2}} \right)^{2/5} \quad (6)$$

In addition, the Magnus force also exists in the rotation of tennis. According to computation of fluid dynamics, during the rotation of the ball in the air, in the case of the flight velocity vector and the rotation angular velocity vector do not coincide, the force to make the motion path of the ball offset on the surface which is perpendicular to translational velocity vector and the rotational angular velocity vector is Magnus force, which can be calculated and analyzed in accordance with the following formula:

$$\overrightarrow{Fm} = \frac{1}{2} Cm\rho A \left|\vec{v}^{\,2}\right| \frac{\vec{\omega}}{|\vec{\omega}|} \times \frac{\vec{v}}{|\vec{v}|} \quad (70$$

In this formula, Cm is a constant, a Magnus force lift coefficient, and Cm<<Cd. Assume that the line speed v and angular rate $\vec{\omega}$ determine the value of Cm, then compute and analyze according to the following formula:

$$Cm = \frac{1}{2.022 + 0.981\frac{v}{\omega}} \quad (8)$$

Make stress analysis on the ball and get formula (9):

$$m\left[\frac{dv_x}{dt}, \frac{dv_y}{dt}, \frac{dv_z}{dt}\right]^T = \begin{bmatrix} \cos\alpha\cos\varphi & \cos\beta\cos\theta & 0 \\ \cos\alpha\sin\varphi & \cos\beta\sin\theta & 0 \\ \sin\alpha & \sin\beta & 1 \end{bmatrix} \quad (9)$$

In this formula, F_d refers to air resistance, G refers to gravity, Fm refers to Magnus force, v refers to translational velocity, the angle between v and flat XOY is α, the angle between Fm and flat XOY is β, the angle between v' s projection on flat XOY and x axis is Φ, and the angle between the projection of Fm on flat XOY and x axis is θ.

3.3. Simulation Based on ODE

3.3.1. Adhesion, Elasticity, Friction

In the experiment, two cylinders make up the sphere geometry of the ball, whose dimensions are (h = 10mm, r = 3.325cm, m = 57.5g). The corresponding physical parameters are obtained from the experiment, including the coefficient of rolling friction, static friction coefficient.

The rotation of tennis is caused by the instant friction when the racket hits the ball. The rotating speed of topspin with 1700RPM and 1800RPM is common in games. Occasionally, it will be higher than and 1800RPM, but such kind of extremely high rotating speed only appears in some exceptional circumstances. In a game, due to the rotation of the ball, it is difficult to identify the accurate movement direction or the movement law, so that the athletes behavior during the race is unpredictable. Therefore, analysis and research on the causes of ball's rotation and its movement laws can help to improve the sports enhancement technology.

In the collision of ball and racket, it will generate contact force (elastic force), so the primary factor for ball's rotation is that there is elastic deformation between the ball and racket and it tends to result in relative movement.

The collision of the two objects will generate static friction force and rolling friction force, between which the static friction force makes the ball rotate at the time it off the racket and move along a straight line, while the rolling friction force is just the opposite. Actually, the rotation of ball will be affected by all these factors such as the roughness and material of contact surface between the ball and racket, collision restitution coefficient, elastic properties.

According to the study, the hardness of the racket has greater impact on the rolling friction force, that is the softer the racket is, the stronger the corresponding rolling friction force will be. When hit back the topspin with a hard wooden board, the rolling friction force is very small, so that the rotation direction of the ball after being hit won't change. But, it seems that the rotating direction has changed for the opponent, thus resulting in false judgment which will lead to catching mistakes.

Establish simulation system on the movement of tennis, and control the hardness on racket through the ERP and CFM. In the hitting process, if it occurs inelastic collision in actual condition, the elastic collision process in the simulation system can be designed through simulating ERP and CFM. In ODE, the collision of ball and racket is regarded as a kind of contact joint, which ca be represented in the following equation:

$$J * v = c \tag{10}$$

In this formula: J——Jacobian matrix； v——speed vector.

$$force = J^T * \lambda \tag{11}$$

In this formula: force——the force to keep joint binding.

The binding equation of ODE gained from the former formula is:

$$J * v = c + CFM * \lambda \tag{12}$$

Here, CFM is a diagonal matrix, in which the resultant of constraint relations is mixed together. When CFM ≠ 0, the system will strengthen the binding to recover the constraint vector; if CFM = 0, the constraint will become rigid constraints; when CFM> 0, the external force can be increased to violate the constraint, for example, two objects can have mandatory contact; the surface softness of CFM and the contact spherical are proportional.

3.3.2. Trajectory

There are three stages for the racket to beat ball: waiting Ts, hitting T_h, returning T_r, wherein the core stage is Th. Assume that the ball flight parameters have already been identified during Ts, and then to determine the two parameters-- hitting position X and the instantaneous velocity V when the racket hits. The position of racket can be identified through the movement path of opponent's ball on the flat(X-Z plane) which is perpendicular to the ground. It can be calculated by the following formula.

$$X_m = X_p + k\left(X_p - X_c\right) \tag{13}$$

In this formula: Xp refers to the predicted hitting position; X_c refers to the corresponding X-axis coordinate of the ball's collision point with ground; k is a parameter, which is adjusted according to the waiting period (Ts).

Integrating the basic geometries in ODE system to form the ground, whose basic dimensions are: 36.6m long, 18.3m wide, and 0.76m high; net's dimensions are: 12.8m wide, 1.07m high, set the coefficient of restitution(r) between the ball and ground as 0.85, and the friction coefficient (f) is 0.71.

3.4. Simulation Collision Detection

To make the result of simulation experiments more close to real movement, collision detection on intersected collision objects are needed in the part of simulation system collision detection. The process is as follows:

1) Users transfer the collision detection function in the system, and the function shifts the space-bar in actual movement into the contact point.

Collision detection.

The main adopted collision detection functions are as follows (o1, o2 are two collision bodies to be tested)

a) dCollide Function, to detect if collision objects intersect or not and input the contact information into the system:

```
dGeomID o1;
dGeomID o2;
int flags;
dContactGeom*contact;
int skip;
```

b) dSpaceCollid function, to identify the possible intersected object pairs and adopt NearCallback function on them.

```
dSpaceID space;
void*data;
dNearCallback*callback;
```

c) dSpaceCollide2 function, as a callback function, it is to identify the intersected objects in different collide spaces.

```
dGemonID o1;
dGemonID o2;
void*data;
dNearcallback*callback;
```

2) Create contact spherical and record the attributes of objects during the collision.

3) Generate an analog step, record the collision information and return it to the user

4) users establish contact connector, represent it in the following data structure:

```
struct dContact
{
dSurfaceParameters surface;
dContactGeom geom;
dVector3 fdir1;
}
struct dSurfaceParameters
{
int mode;
dReal mu;
dReal mu2;
dReal bounce;
dReal bounce_vel;
dReal soft_erp;
dReal soft_cfm;
dReal motion1,motion2;
dReal slip1,slip2;
}
```

For general coupling, the method to process separately is: simulate the binding effect caused by analog step's exerting coupling on objects, then adopt kinetics engine to gain the size of corresponding binding force, so as to keep the joints relationship among the moving objects. Coupling constraint equation is as follows:

$$v_1 + \Omega_1\omega_1 + J_2 v_2 + \Omega_2\omega_2 = c + C\lambda(l \le \lambda \le h) \tag{14}$$

Wherein, V1, v2, ω1、ω2 are all 3 * 1 vectors, respectively refers to linear velocity and heading variation amount; J and Q are the Jacobian matrix; c is the m * 1 vector; C is the diagonal matrix of m * m (binding reconcile matrix), which is usually set as 0; λ is the m*1 constraint vector.

4. Experiment and Analysis on the Results

4.1. Static Experiment

To test the authenticity and accuracy of the simulated simulation experiment platform, carrying out experiment on dropping ball from different heights to measure the bounce height, and then compare the measured height and the corresponding bounce height under different elastic coefficient on simulation platform. It is showed in Figure 5:

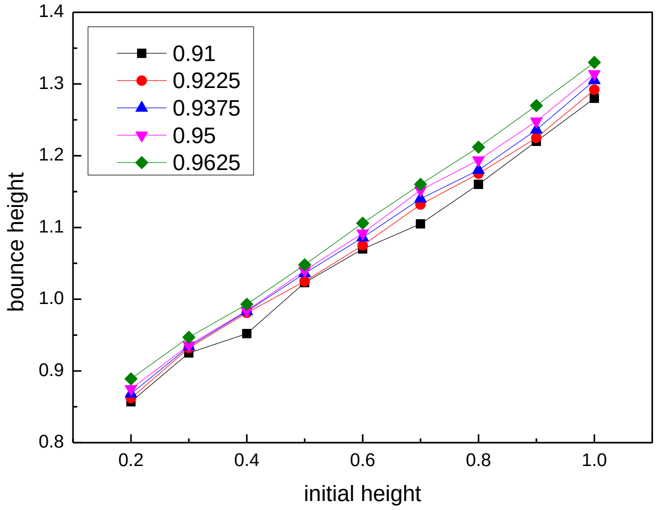

Figure 5. The Contrast Curve of Measured Bounce Height and the Bounce Height in Different Elastic Coefficient

In this picture, the curves respectively reflect different elastic coefficient, among which the red one refers to the measured value. Form the curve; it is obvious that when the set elastic value is 0.9625, the resulting value of simulation experiment platform is the same with measured value. In this period, accurate simulation can almost be made.

4.2. Simulation Experiment

Under Magnus force, the trajectory of spinning ball is an arc, and the higher the speed is, the greater the degree of arc's bending is. To prove the correctness of this law, simulation experiments are carried out on side spins whose spinning speed is between 500RPM and 3600RPM. Taking the features of simulation experiment platform and the maximum smash speed of athletes into consideration, the beat range of 600Hz ~ 4800Hz is adopted. The simulation environment is: AMD AthlonIIX2 2.9GHz CPU 2G RAM, WinXP operating system. Setting an initial value: h = 1m, ω = 160r / s, v = 10m / s, the elevation is 0.06rad, ball position is set at a place where has a distance of 6.4m to one side of the net on the ground.

The result of experiment is showed in Figure 6 and Figure 7:

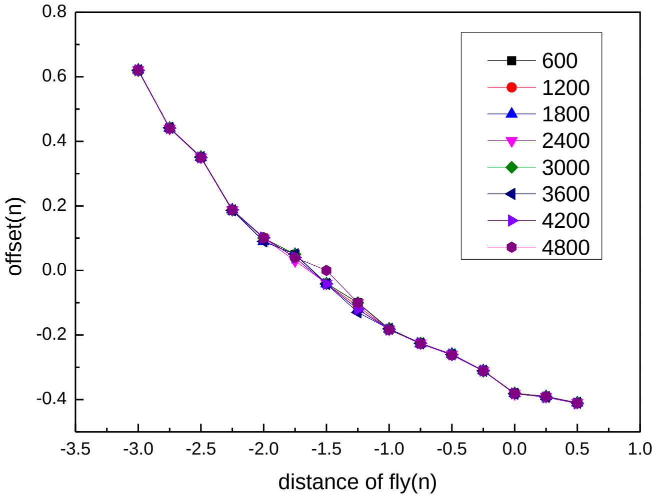

Figure 6. The Horizontal Flight Path of Different Beat

According to this picture, when the beat is higher than 500Hz, the deviation distance of ball and its flight curve coincide, which reflects that Magnus force and air resistance measurements are much more accurate, almost no simulation error.

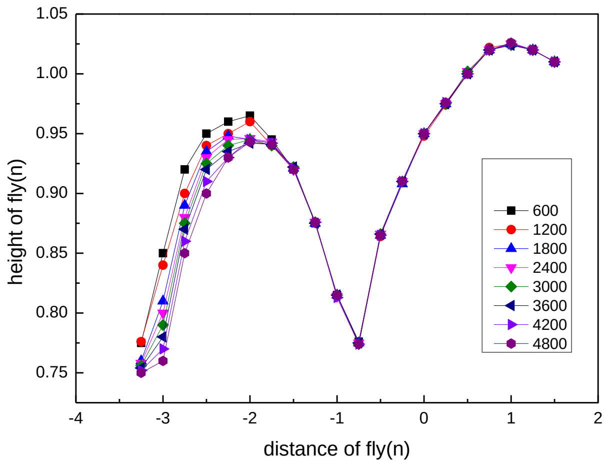

Figure 7. Vertical Plight Path of Different Beat

According to the picture, the orbits almost coincide when the beat is higher than 3000Hz, and the simulation deviation under gravity can be ignored.

5. Conclusion

In this paper, based on VR simulation technology, it makes an in-depth exploration and research on sport competitions, setting the tennis as an example. Setting up a dynamics model on the basis of classical mechanics and related kinetic theories, applying the design of open source physics engine and achieving the interactive and real-time simulation platform based on ODE, and through static test, simulation and collision detection, this paper proves the fact that this platform can help to make accurate and scientific simulation, whose result is accurate, stable and highly operative.

With the wide application of virtual reality technology, in terms of sports training, the shortcomings of traditional training methods can be made up for to the maximum, and mechanical visualization is implemented, so that the data structure and the relationship between the relative motion of the ball movement is more intuitive and concrete. Moreover, with the further development of sports training, a lot of competitive sports has been gradually approaching the limits of human body. Therefore, in the development environment of high-level, high-difficulty, high-precision and high goals, the scientific training process seems to be particularly important. This paper provides corresponding theoretical guidance for athletes to improve their score and make breakthrough. Making experimental simulation on the training process in advance and integrating the collected data through virtual environment and the assessment of physiological indicates can effectively prevent athletes from training injury in improper training, effectively avoid risks, thus greatly improving the level of sport competitions as well as the level of scientific training. Another important factor which can affect athletes is the stadium environment. This paper makes simulation on tennis stadium court, net and something else through three-dimensional scene rendering engine, which can improve athletes’ spot tactical level and raise the sport level on a scientific basis. Therefore, it has a extremely broad prospect to make further research on the application of virtual reality technology in the field of sport competitions.

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