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Research Article

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Triple jump technical motions diagnostic research based on hanavan model bar figure analytical approach

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ABSTRACT

For sports events technical research, it is indispensible to extract apparatus and human each segments status data during movement process. While sports all happened in 3D space, though it can be regarded as planar movement by some hypothesis and ignoring partial errors, plane analysis will not adapt in some complicated sports trajectory project analyzing. This paper selects triple jump technical motions as 3D image analysis research objects, so as to achieve the purpose of exploring sports skills objective laws and technical diagnosis through extracting athletics events technical parameters with scientific 3D track image analytic system. During research process, firstly it analyzes 3D track image analytic system's sports data extracting flow and test methods, then layouts test apparatus in court respectively to man triple jump sports and woman high jump sports by the analysis method, and calibrates system apparatus, finally gets two kinds of sports process bar figure athletes status and biomechanical as well as kinematic parameters through 3D image analysis, which provides data basis for reasonable and precise sports analysis together with research methods for technical diagnosis.

Key words: 3D image analysis, frame calibration, motions analysis, technical diagnosis, hanavan model

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INTRODUCTION

3D track image analytic system is an important way for sports techniques biomechanical and kinematic analysis. In recent years, human track techniques are widely used in virtual reality, video compression, man-machine interaction, motion capture and sports analysis. Due to human sports is non-rigid, while kinematic parameters analysis takes rigid body as model which is also the best and precise research model, so it needs the reasonable influence analytic system that is the way getting human each status bar figure modes through 3D sports analysis of non-rigid human sports status. For high jump and triple jump such two events in athletics, 3D track image analysis is a good research method.

For 3D track image analytic researches, lots of people have made efforts, by whose research methods and design ideas propels each field microcosmic technical research, similarly provides scientific reliable research methods for the development of sports analysis. Among them, Deng Yu etc.(2009) Through defining 3D human model, camera model as well as observing likelihood model, gets objective functions that track requires, and uses optimized particle filtering algorithm to make solution, which makes contributions to sports analysis[1]; Cai Jie etc.(2009)For human sports trajectory fast table and human self-occlusion phenomenon, they put forward a human sports track algorithm based on 3D Kalman filter and human constrains, and verify its scientificity and accuracy by experiments[2]; Lv Zhi-Guo etc. (2012) according to human hands physiological motions constrains establishing human hands dynamic model, present that adopt hierarchical genetic optimization method to fast look for partial good particles, and use them as samples functions, proof the method reasonability to human hands tracking by patterns [3].

This paper based on previous research, carries out 3D track image analysis of man triple jump and woman high

jump in athletics events so as to make contributions to propel sports analysis.

RESEARCH OBJECTS, RESEARCH METHODS AND ANALYSIS FLOW

Take excellent triple jumpers as research objects; adopt 3D sports image analysis and sports biomechanical analysis methods. Apparatus applied: SIMI Motion 3D image analysis system with 3D track scan function module, one digital camera Sony DCR-HC52E and one Panasonic NV-GS55,one set of calibration framework, one Topcon GPT-3002N total station, one objective observation and coordinate frame conversion software system and laptop, one set of self-processing additional control point as well as other forms installation apparatus [4].

Analysis Flow: 3D track scan image analysis is with the purpose of recording sports images through camera tracking sports objects, by special image analysis system effecting on sports objects actual 3D coordinates, which is required to set camera rack on the fixed tripod, then camera can swing in four directions surrounding vertical axis and horizontal axis, the above two functions can guarantee camera track sports objects in shooting process, meanwhile adjust focus during shooting process enable that it can form sports objects into images as much as possible, its test analysis flow conditions as Figure 1 shows.

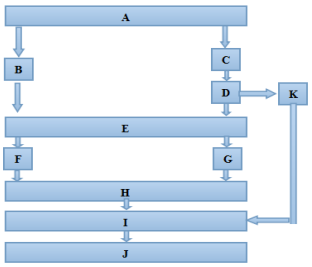

Figure 1: 3D track image analysis flow

Definitions from A to K in Figure 1 are as Table 1 shows.

Table1: 3D track influence analysis flow figure's signs definitions

Sign	Definition
A	According to events motion features set additional control points, 3D calibrate frame and video location
B	At least use two cameras to shoot 3D calibration frame
C	Total station to measure additional control points 3D coordinates
D	Convert additional points coordinate into calibration frame defined coordinate system
E	Utilize 3D track scan function module's SIMI Motion 3D sports image analysis
F	Analyze 3D calibrated frame's video images
G	Input control points coordinate into database to manage
H	Analyze sports technical images
I	Through calculation get 3D kinematic parameters in calibration frame defined coordinate system
J	Make translation and rotation to coordinate system according to analysis requests, get new coordinate system kinematic parameters through calculation
K	Work out coordinate system translation and rotation parameters

ATHLETICS MAN TRIPLE JUMP 3D TRACK IMAGE ANALYSIS

Triple jump image analysis testing process

The apparatus layout conditions in triple jump court is as Figure 2 shows, from which 10 control balls put along the runway, 5 control balls put along the jumping pit, distance that No. 1 control ball to No.15 control ball from Y axis direction that defined by calibration frame is 24.5m. Total station is needed to put between two cameras so as to ensure can shoot the 3D frame coordinate origins 0, point I in X direction and point j in Y direction.

First use total station, control point targets observation and coordinate frame conversion software system to take 3D data measurement on 15 additional control points, and convert these data into 3D coordinate data in coordinate system that defined by calibration frame, as Table 2 shows additional control points 3D coordinate data in coordinate references that defined by calibration frame [5, 6].

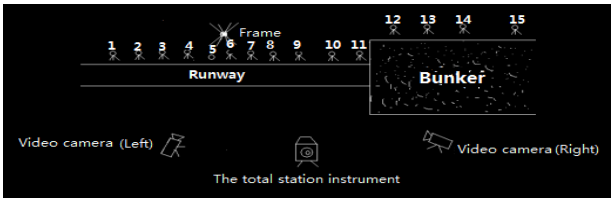

Figure 2: Triple jump court test equipment layout schematic diagram

Table 2: Additional control points 3D coordinate data in coordinate reference system defined by calibration frame table

Control point	X axis coordinate	Y axis coordinate	Z axis coordinate	Control point	X axis coordinate	Y axis coordinate	Z axis coordinate
O	0.0000	0.0000	0.0000	7	1.5303	3.4876	-0.2529
i	1.9011	0.0000	0.0000	8	1.4571	5.6500	-0.1907
j	0.0256	2.2547	0.0000	9	1.4027	7.7381	-0.1442
1	1.8231	-6.7694	-0.5259	10	1.3474	10.1318	-0.0831
2	1.7521	-4.7408	-0.4712	11	1.2676	12.4505	-0.0234
3	1.7019	-2.8992	-0.4135	12	-0.6038	14.2785	0.0237
4	1.6211	-1.1344	-0.3677	13	-0.6449	16.1150	0.0718
5	1.0667	0.1784	-0.4513	14	-0.6697	17.7401	0.1169
6	1.5921	1.2057	-0.3170	15	-0.7668	21.5309	0.2203

Use two units of cameras to shoot 3D calibration frame, and scan track shooting athletes completed technical motions when they complete technical training, shoot frequency of camera is 50HZ.

Technical motions analytical analysis

Sports process of athletes completing 15.75m sports performance is analyzed by SIMI Motion 3D sports image analysis system which possess of 3D tracking scan function modules. To make a better analysis of human motions, it needs to handle human status at one moment of sports into 3D bar figure. This paper utilize s Hanavan model calculating body each segment and gravity center, and take digital low-pass filter's smooth treatment to original data. Through calculation can get triple jumpers technical diagnostic 3D kinematic parameters, front and side face 3D bar figures and sloping side included gravity center changing laws 3D bar figure of the analyzed triple jumpers' 3 steps and 3 jumps whole process after run-up, are like Figure 3 showing triple jump front and side face 3D bar figure, Figure 4's triple jump sloping face 3D bar figure and gravity center trajectory schematic figure. From below two pictures, it can easily analyze athletes' kinematic parameters during this process.

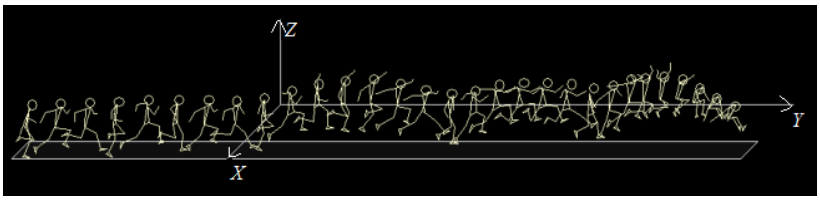

Figure 3: Triple jumpers' last 3 steps and 3 jumps process front and side face bar figure definition conditions

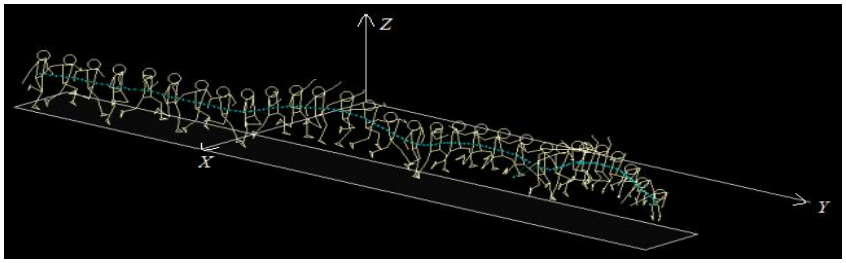

Figure 4: Triple jumpers' last 3 steps and 3 jumps process sloping face bar figure and gravity center trajectory conditions

Triple jump process biomechanical parameters analysis

From analysis result of triple jump 3D track scanning image analysis system, it can get the key biomechanical parameters that coaches and learners required.

Run-up last 3 steps' step length affect jumpers' three jumps process playing to some extent. In order to research run-up last 3 steps conditions, analysis system takes the last 3 steps' step length values, as Table 3 shows.

Table 3: Run-up last three steps' step length value table

Number of step	Bottom third step	Bottom second step	Bottom first step
Step length	2.43 m	2.18 m	2.24 m

From Table 3 data can know that run-up last 3 steps length are basically the same, it changes under the law from big to small then to big, and such pace is helpful for propelling the first jump normal playing in three jumps. In three jumps process, every jump would affect the final result, it needs to make reasonable arrangement of proportions of distances among three jumps. Generally speaking, the first jump is run-up supplies the main energy, due to longer run-up distance more energy stored, therefore the first jump should arrive at the maximum distance; while in second jump, run-up energy has been mostly consumed that cannot effective supply energy for it, while the second jump is also the medium that connects with the third jump, so the second jump takes energy storing as main task, and takes distance as secondary one, therefore distance between the second jump and the third jump should be minimum. The third jump by partial run-up energy and also stored energy from the second jump process, it should have a wonderful playing that goes beyond the second jump by distances that produced. In order to carry out data verify on three jumps distances, it gets 3 jumps distances and their proportions status by 3D analysis system in this paper, as Table 4 shows.

Table 4: Three jumps process each jump produced distance table

Three jumps types	Hop	Step	Jump
Jump distance	5.79 m	4.32 m	5.64 m
Proportion	36.8 %	27.4 %	35.8 %

In three jumps process, the direct factors that constrained each jump distance is the takeoff speed and takeoff angle, triple jumper pursuits the faster takeoff speed and reasonable takeoff angle. Due to trajectory that jumpers human gravity center streaked in takeoff process are roughly a parabola. In order to have a longer distance in horizontal direction and without leaning back body when landing, it needs to have a correct reasonable seize on speeds and takeoff angles. In this paper, it through 3D analysis system get three jump process pedal speed, takeoff speed as well as takeoff angle, the result is as Table 5 shows.

Table 5: Table of human gravity center speed conditions in pedal moment, takeoff moment during three jumps processing

Takeoff state	Hop		Step		Jump	
	Pedal moment	Takeoff moment	Pedal moment	Takeoff moment	Pedal moment	Takeoff moment
Horizontal speed	8.70 m/s	7.96 m/s	7.50 m/s	6.72 m/s	6.68 m/s	5.57 m/s
Vertical speed	0.12 m/s	2.56 m/s	-0.85 m/s	1.80 m/s	-1.28 m/s	2.56 m/s
Takeoff angle	17.8°		15.0 °		24.7 °	

ATHLETICS WOMAN HIGH JUMP 3D TRACK IMAGE ANALYSIS

High jump image analysis test process

During high jump image analytical data test process, firstly it should fix 3D coordinate frame well, then put it in the middle of bar, then place a set of 16 additional control points along jumpers' runway, respectively carry one control point little ball in the bar's top left, bottom left, top right and bottom right, finally layout camera and total station well, and make bus link between total station and computer and let it can communicate. The layout location of cameras should be in the left side of bar and forms 30 degree and 80 degree included angle with bar's left side, adjust handle bar to let camera can swing left and right surround vertical axis, meanwhile stuck frontal axis to avoid it swing up and down, total station should be put between two cameras so as to ensure that can shoot the 3D frame coordinate origins 0, point i in X direction and point j in Y direction, and high jump on site apparatus layout status as Figure 5 shows.

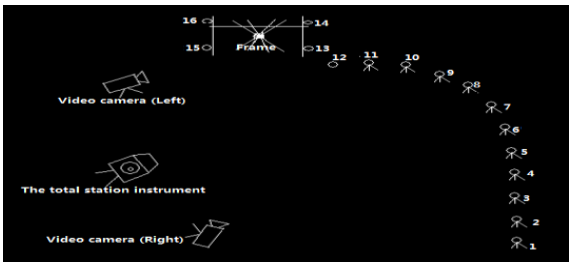

Figure 5: High jump court test apparatus layout schematic figure

Similarly utilize two cameras to shoot 3D frame, and use total station and control point targets observation and

coordinate frame conversion software system get 16 control points 3D coordinates as Table 6 shows.

Table 6: Additional control points 3D coordinate data in coordinate reference system defined by calibration frame

Control point	X axis coordinate	Y axis coordinate	Z axis coordinate	Control point	X axis coordinate	Y axis coordinate	Z axis coordinate
i	1.9067	0.0000	0.0000	8	-0.0795	-6.0098	-0.4609
j	0.0262	2.2565	0.0000	9	1.0642	-5.0565	-0.4177
1	-14.0427	-7.0717	-0.7981	10	1.6915	-3.6439	-0.3848
2	-11.8865	-7.1001	-0.7413	11	2.0924	-2.4424	-0.3552
3	-9.8909	-7.2377	-0.6922	12	2.2336	-1.4433	-0.4373
4	-7.8121	-7.2618	-0.6466	13	2.0712	-0.4319	-0.0195
5	-5.6503	-7.3453	-0.5996	14	2.0854	-0.4449	1.7123
6	-3.7218	-7.1805	-0.5564	15	2.1506	3.6754	0.5013
7	-1.7338	-6.8189	-0.5093	16	2.1677	3.6597	1.7643

Technical motion analytical analysis

Firstly shift 3D frame location, jumpers start trial jumping after completing warm-up, utilize apparatus and 3D image analysis system that mentioned in this paper to carry out track analysis of woman high jumper's high jumping whole process, then similarly apply Hanavan model to calculate each body segment and gravity center, and take digital low-pass filtering smooth treatment to original data, can get bar figure schematic figure as Figure 6 shows.

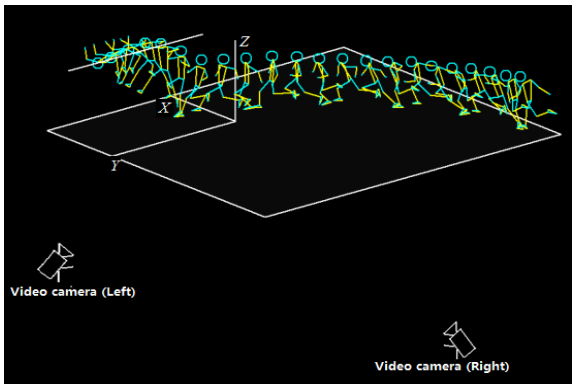

Figure 6: High jump each status jumpers bar figure schematics

3D coordinate value got through analysis is the coordinate data in calibration frame defined coordinate system. Due to calibration frame is fixed on tripod, frame coordinate system origin have a certain distance from ground in vertical direction, frame coordinate system XOY plane is not parallel with horizontal plane, only take secondary treatment of data can get analytical research needed data. For above questions, SIMI Motion 3D analytical analysis system's coordinate translation and rotation function can solve them. In order to verify data changing status after leveling coordinate reference system, specially make comparison on calculated height before and after leveling, as Table 7 data shows that coordinate reference system after leveling cross-bar height is more approximate to actual cross-bar height.

Table 7: Before and after leveling cross-bar height calculation value comparison status

Coordinate reference system state	Left endpoint	Right endpoint
Before leveling	1.921 m	1.892 m
After leveling	1.885 m	1.856 m

High jump process kinematic parameters analysis

In high jump trial process, jumpers can take trial, sometimes can jump over successfully while sometimes will failed in trial. Through 3D track image analysis system in high jump process can get succeed jumping and failed jumping two situations jumpers starts from last 5 steps to jumping ends jumpers' human biomechanical parameters, if make comparison of them and show it to high jump researchers that can make contributions to high jump technical improvement.

Distribution status of run-up last five steps' step length affect the success of takeoff, as Table 8 shows failure and success two situations' jumpers last 5 steps' step length distribution status.

Table 8: Jumpers' last 5 steps step length comparison under failure and success two conditions

Pace	Bottom fifth step	Bottom fourth step	Bottom third step	Bottom second step	Bottom first step
Success	2.13 m	1.93 m	1.69 m	2.24 m	1.97 m
Failure	1.99 m	2.04 m	1.86 m	2.05 m	1.80 m

Due to human can through body rigid structure covert its own horizontal speed into vertical speed in high jump takeoff process, that is to say takeoff first five steps' human gravity center horizontal speed affects takeoff height, average speed status of each step from last five steps affect whether takeoff is successful or failed to some extent. In the paper, it through 3D track image analysis system get average speed of each step out of high jump run-up last five steps under takeoff succeeding and takeoff failed two statuses. There comparison results are as Table 9 shows.

Table 9: Human gravity center horizontal speed two statuses data comparison in high jump run-up and takeoff process

Pace	Bottom fifth step	Bottom fourth step	Bottom third step	Bottom second step	Bottom first step	Pedal jumping	Takeoff
Success	5.96 m/s	6.34 m/s	6.72 m/s	6.70 m/s	6.52 m/s	5.99 m/s	3.90 m/s
Failure	5.98 m/s	6.28 m/s	6.33 m/s	6.74 m/s	6.37 m/s	6.13 m/s	4.03 m/s

Analysis of takeoff vertical speed, takeoff horizontal speed and takeoff angle such three factor which directly affect whether high jump succeeded or failed can make more detailed exploration on high jump techniques, 3D track image analysis system collects the three kinematic parameters as Table 10 shows.

Table 10: High jump takeoff stage speed and angle data comparison under failure and success

Takeoff parameter	Vertical speed	Horizontal speed	Takeoff angle
Success	3.399 m/s	3.895 m/s	41.11 °
Failure	3.459 m/s	4.030 m/s	40.64 °

Success high jump outside presentation is distance, which is also vertical directions displacement and cross-bar height as well as relative other height data, these parameters can similarly get by 3D track image analysis system analytical data, as Table 11 shows.

Table 11: Data comparison of high jump takeoff process space displacement under failure and success two statuses

Height value sorting	Maximum height	Soar height	Bar-over height	Cross-bar height	Takeoff height
Success	1.896	0.639	0.026	1.870	1.257
Failure	1.899	0.625	0.021	1.878	1.274

CONCLUSION

This paper utilized 3D track image analysis method, took athletics man triple jump and women high jump as research examples, made detailed introduction of analysis method applying steps and apparatus layout. In the paper, it provided 3D track image analysis system's sports data extraction test flow, stated necessity and nature of measurement apparatus. In athletics sports features analysis, according to athletics different events features such as sprint, long jump and high jump's differences, use 2D image analysis of sprint and standing long jump can get data that researchers need, while triple jump, high jump and throwing events due to their movement trajectory not happened in a plane, therefore it need to use 3D image analysis system. In 3D sports analysis system, calibration frame defined plane is not always parallel to horizontal plane, therefore it need to calculate frame's leveling parameters when using total station control points targets observation and coordinate frame conversion software system.

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