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Two-dimensional image technology-based arm three-dimensional reconstruction application in discus throw technical motion analysis

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ABSTRACT

The paper takes discus throw movement process's throwing arm as research objects, on the basis of stating movement process and its force analysis, it explores rotational arm two-dimensional image-based analyzed three-dimensional reconstruction system, in the hope of providing theoretical basis for sports analysis. For discus throwing basic technical motion, it makes analysis and states discus throwing process human movement postures, focuses on researching throwing arm trajectory features in rotation process and discus force status. Based on two-dimensional image three-dimensional reconstruction process principle, it gets rotation arm projection in three planes after three-dimensional reconstruction, and then applies projection and material object relations, it gets three-dimensional reconstruction final model. In video tracking technology, human skeleton shape extraction and articulation joint extraction methods, it provides video camera articulation point calibration methods, by video camera obtained two-dimensional image after calibration, and calculates three planes projection.

KEYWORDS

Computer vision; Video track; Projection; Discus throw; Arm motion.

INTRODUCTION

In current sports analysis, lots of researchers are based on video analysis. It is well-known that video image is two-dimensional image, and human movement locates in three-dimensional space. Although two-dimensional video image promotes sports technological level improvement to a certain degree, people are more interested in human three-dimensional sports analysis. It is because three-dimensional analysis can comprehensive specific present movement features, and can also provide more scientific improvement measures for sports training.

Chen Shu (2008) pointed out as one of oldest competitive sports, discus throwing movement has already gone through centuries of exposure, its records have been renewed, and by far its performance has been difficult to break through. Generally speaking, human can be expressed by its contour, edge, movement, color and others in images[1]. Wang Jun-Cang (2009) put forward three-dimensional reconstruction was one of main contents of computer vision technical researches, in engineering techniques and sports analysis, usually it should carry on three-dimensional analysis of objects, and then get useful information for researching, and two-dimensional image-based three-dimensional reconstruction technique was key links of the research[2]. The paper takes two-dimensional image three-dimensional reconstruction as research contents, analyzes discus throwing movement process throwing arm three-dimensional reconstruction principle, with an aim to provide theoretical references for China's sports technical development.

For discus throwing process, arm movement features and arm movement two-dimensional image's three-dimensional reconstruction researches, lots of people have made efforts, from which Wang Guo-Wei and others (2014)applied three-dimensional shooting and interview and other methods to analyze discus throwing movement process athletes' rotation acceleration type, and analyze "quick-quick-slow-quick and quick-quick-quick-quick" two types[3]. Zhang Dong-Hai (2013)designed and made biplane calibration frame, utilized computer iconology method to make computer recognition on frame calibration, and implemented movement analysis three-dimensional reconstruction frame automatic recognition[4].

The paper based on former researches, utilizes computer vision and video observation projection technology to reconstruct discus throw event arm motion, it provides a kind of effective and convenient method for future sports researchers, and meanwhile builds theoretical basis for two-dimensional image video's three-dimensional reconstruction.

DISCUS THROW EVENT BASIS MOTION FEATURES MECHANICAL ANALYSIS

In Olympic Games and world athletics championships' strength type competition events, discus throw event occupies more important position. The sport event requires athlete to use one hand to grip discus, and throw discus out, measure distances with regulated directions, pursuit of " further". Discus throw movement process needs to well grasp gripping method, preliminary postures, pre-swing postures, final exertion and body balance after discus throwing these five parts, in the hope of letting discus to get maximum release speed by rotational motions in throwing circle, and let discus to get maximum throwing distance.

Discus throw not only requires athlete to possess stronger power, but also needs athletes to well grasp rotational technique and final exertion technique, only in this way then can let athletes to give powerful explosive power into play, in the hope of fulfilling discus throwing, and meanwhile let discus to get largest distance. This chapter divides two sections to analyze discus throwing event basic movement, arm chucking trajectory and arm force status, in the hope of building basis for throwing arm image reconstruction.

Basic motion introduction

Discus throwing process is a relative complicated movement process, roughly includes gripping method, preliminary posture, pre-swing, rotation and final exertion five contents, the paper intercepts 13 key links human movement postures from discus throwing movement process videos, displays discus throwing movement process as Figure 1 shows, in the hope of providing basis for discus throwing process arm exertion and whole body movement correlation.

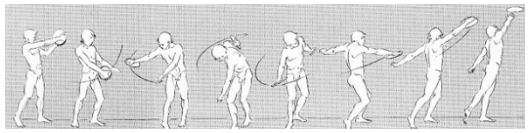

Figure 1 : Discus throws process continuous human posture

As Figure 2 shows, in discus throwing process, athlete's discus specific gripping form schematic diagram.

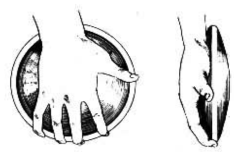

Figure 2 : Discus gripping method

As Figure 3 shows, in discus throwing process, athlete preliminary posture schematic diagram.

Figure 3 : Preliminary posture

In Figure 1, it shows gripping method, preliminary posture, pre-swing, rotation and final exertion five items contents' athlete human posture status. In order to more clearly shows athletes discus gripping method and their preliminary postures in discus throwing process, it provides two schematic diagrams as Figure 2 and Figure 3 show. In Figure 1, pre-swing is to get preliminary speed, and provide elastic potential energy. Common pre-swing has left upward right backward discus swinging method and body forward and backward discus swinging method two ways, from which body forward and backward discus swinging method movements are relaxed, range is big and is simpler and convenient, therefore it becomes present most athletes adopted pre-swing ways. In Figure1, rotation and final exertion are a kind of process with full of explosive powers, excellent rotation and final exertion are usually done at one go. Rotation and final exertion process occur after pre-swinging ending, their essential of exercises are as following:

- Firstly, bended right leg pedals ground.
- Then, it is upper body rotates, uses left leg pedaling strength to push body to move towards center of throwing circle, let body to lie in the twist tightening state.
- Next is to concentrate whole body strength in discus, let discus to rotate in clockwise direction and flight forward.
- Finally, it is maintaining balance stage.

After discus is throwing and out of hand, whole body strength will concentrate on throwing arm, if body cannot keep balance, it will easily cause losing points or sports injury, therefore, athlete should instantly alternate two legs, control body to rotate leftward, and at the same time, reduce body gravity center, let body to remain balance, after body being stable, discus throwing movement fulfil.

Athlete throwing arm movement trajectory and its force analysis

In order to analyze discus throwing distance, it needs to start from physical parameters that decide its distance that is initial speed after discus being released, we know speed is a vector; it includes size and directions, if discus horizontal speed arrives at expected maximum value after releasing, then it can get an expected distance. And after discus releasing, angular parameters are up to throwing arms movement trajectory, speed size parameter is up to throwing arms exertion strength. Therefore, in order to more targeted research on discus throwing movement, the section analyzes throwing arms movement trajectory and its force status.

By previous analysis, it is clear to get discus maximum throwing distance; it needs horizontal speed to be big enough when discus being released, so it is very strict with arms strength distribution and movement requirements. To increase arms strength, it should try to reduce arms vertical directions force, and increase horizontal direction force by rotating and other movements, and then gets maximum discus horizontal speed. As Figure 4 shows, discus thrower rotation process discus force analysis schematic diagram.

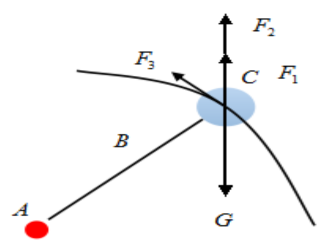

Figure 4 : Discus force in rotation process

Figure 4 shows discus force analysis in rotation process. Each symbol in figure definition is as following:

A shows human shoulder, the position is arms rotating axis center position.

B shows arms shape, it provides force and supporting functions in rotation process.

C shows discus, which is also speed transferring final point.

G represents discus gravity.

F_1 shows that arms give discus an upward acting force.

F_2 represents rotation process arms provided discus upward drag force in rotating direction.

F_3 is a force along discus movement direction that arms provide discus, which is also movement trajectory force in tangential direction. In rotation process, discus movement trajectory roughly is circular movement that is shoulder axis-centered, and with arms as radius. F_1 is active force that is generated by muscle contraction, while F_2 and F_3 are tension that muscle generates through muscle extending in rotation process. Force acting direction is F_2 and F_3 that both discus throwing direction's force that is force to promote discus speed increasing, while F_1 and discus throwing direction opposite force is called inefficacy. By force analysis, it can get relationship as formula (1) shows:

$$F_1 + F_2 + F_3 \cos\theta = G + F_3 \sin\theta \quad \textbf{(1)}$$

Obviously, by formula (1), it is clear that discus lifting and declining extents are up to F_1, F_2 and F_3 as well as G, if it can increase force F_2, then it will appear effect that F_1 diminishes, if exertion is proper, it will appear case that F_1 reduces to zero. So, it can implement arms rotation when arms don't active exert, so that it also can let discus to get big horizontal speed as much as possible in throwing instant, and let discus to arrive at maximum distance.

DISCUS THROW'S THROWING ARMS ROTATION PROCESS THREE-DIMENSIONAL RECONSTRUCTION

Discus throwing event throwing arms three-dimensional reconstruction is main content of the paper studies, the chapter two contents are paving the way for the Chapter contents. Throwing arms three-dimensional reconstruction is helpful for discus coaches improving instruction method, and can provide more scientific method for motions details extraction.

Therefore, in order to more vividly extract athletes throwing arms movement features in rotation process, it needs to apply high technological ways to record athletes movement tracking trajectory, so that can meticulous, clearly and correctly learn athletes technical movements, by calculating angle, speed, accelerated speed and gravity center coordinate and other kinematics parameters, explore athletes movement drawbacks in rotation process, in the hope of providing scientific and comprehensive data for the event researcher and making contributions to athlete training level improvement.

In order to implement throwing arms rotating process three-dimensional reconstruction, the chapter firstly summarizes human body movement video tracking, and then for throwing arms articulation point calibration principles, it makes analysis, and finally provides throwing arms three-dimensional model projection formed method and theory.

Human body movement video tracking summary

Yang Feng (2005) put forward general biomechanics model regarded human body as a multiple rigid system that was connected by joints, each segment had self-parameters as length, mass and inertia so on[5]. Generally apply skeleton model that is composed of joints and human model each joint kinematics parameters reflects human shape, the paper just adopts linear structure with shoulder axis as root node to show arms skeleton structure when throwing discus. In Figure 5, it shows skeleton model's each joint freedom degree distributed a schematic diagram, symbols definitions in figure respectively are 1 represents wrist, 2 represents elbow, 3 represents shoulder.

Figure 5 showed skeleton freedom degree is 3, so it can set state variable as $\phi_t = R^3$, ϕ_t represents definite human body arms skeleton state variable at t instant.

The model describes body appearance that is human body outline, arms after projection is used to compare with image bottom features. The paper applies the shape, uses skeleton's round dot to express arms each part, which basically shows each part connection relations.

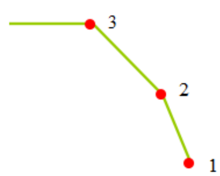

Figure 5 : Arms skeleton model

Human movement tracking process should firstly intercept movement parts that need to research from videos, and then start tracking and positioning on human body every point, connect every point into edge line, and then connect to plane, and even compose a three-dimensional individual. Complete such a series of works then fulfill human body movement tracking, and implement movement process reconstruction of human body.

Throwing arms articulation point calibration principle analysis

In calibration model ideal pinhole camera model when calibrated human body is parallel to camera imaging plane, establish world coordinate system $(O_W X_W Y_W Z_W)$ $X_W Y_W$ plane in calibrated human body parts, establish Z_w coordinate axis in calibrated human body plane's tangential direction, set space point P coordinate under the coordinate system is $(X_W Y_W Z_W)$. Camera coordinate system

$(O_C X_C Y_C Z_C)$ coordinate origin is optical center point of camera, X_C coordinate system and Y_c coordinate system are respectively parallel to X_W coordinate system Y_W coordinate system, and take optical axis Z_C as coordinate system, point coordinate is represented as (X_C, Y_C, Z_C). Set human body surface one point x belongs to node x_n, and x in node x_n coordinate system partial coordinate is x^j. Take positive direction movement equation as theoretical basis, apply posture parameter to calculate x transformation matrix m_{x_n} between coordinate system and world coordinate system, as Figure 6.

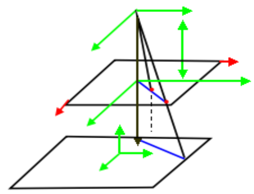

Figure 6 : Calibration target surface imaging plane camera calibration model

Transformation from world coordinate system to camera coordinate system coordinate, convertion from $O_W X_W Y_W Z_W$ to $O_C X_C Y_C Z_C$ are three-dimensional space rigid transformation, if set R and T respectively to be rotation matrix and translation matrix, as formula (2) shows:

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = R \begin{bmatrix} X_W \\ Y_W \\ Z_W \end{bmatrix} + T = \begin{bmatrix} r_1 & r_2 & r_3 \\ r_4 & r_5 & r_6 \\ r_7 & r_8 & r_9 \end{bmatrix} \begin{bmatrix} X_W \\ Y_W \\ Z_W \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix} \quad \textbf{(2)}$$

If use formula (3) showed symbol to replace trigonometric functions, and then according to right hand rule, make small rotation on camera, then rotation matrix uses eulerian angles to express as formula (4) :

$$[\sin\alpha \;\; \sin\beta \;\; \sin\gamma \;\; \cos\alpha \;\; \cos\beta \;\; \cos\gamma] = [A \;\; B \;\; C \;\; D \;\; E \;\; F] \quad \textbf{(3)}$$

$$R = Rot(z,\alpha)Rot(z,\beta)Rot(z,\gamma) = \begin{bmatrix} DE & DBC - AC & DBF + AC \\ AE & ABC + DE & ABC - BD \\ -B & EC & EF \end{bmatrix} \quad \textbf{(4)}$$

In case calibrated plane is parallel (or approximately parallel) to video imaging plane, α and β values are very small, it is thought that following several approximate formulas are true : $\cos\beta \cong 1 \Rightarrow \sin\beta \cong \beta; \cos\gamma \cong 1 \Rightarrow \sin\gamma = \gamma$

Besides, α and β product value is infinitely small, it can be ignored. So formula (4) can be expressed as formula (5):

$$R = \begin{bmatrix} \cos\alpha & -\sin\alpha & \beta\cdot\cos\alpha + \gamma\cdot\sin\alpha \\ \sin\alpha & \cos\alpha & \beta\cdot\sin\alpha - \gamma\cdot\cos\alpha \\ -\beta & \gamma & 1 \end{bmatrix} \quad \textbf{(5)}$$

In case calibrated plane is parallel (or approximately parallel) to video imaging plane, calibrated target surface all calibrated points' Z_w is the same and on the basis that it will not affect calibration result, it can set $Z_w = 0$, so it can get formula (6):

$$\begin{cases} X_c = X_W \cos\alpha - Y_W \sin\alpha + t_x \\ Y_c = X_W \sin\alpha + Y_W \cos\alpha + t_y \\ Z_c = -X_W\beta + Y_W\gamma + t_z \end{cases} \quad \textbf{(6)}$$

When ignore camera distortion, image point coordinate in image plane coordinate system is $P_U(X_U, Y_U)$, image point coordinate in image plane coordinate system is $P_d(X_d, Y_d)$, position in computer frame stored images is $m(u,v)$, camera basic task is establishing $P_W(X_W, Y_W, Z_W)$ and $m(u,v)$ definite relations.

Camera parameters initialization steps are as following:

STEP1. Make initialization on camera internal parameters.

STEP2. Make initialization on camera external parameters.

Among them, in STEP1, it needs to first input plane calibration target calibration point three-dimensional coordinate and image coordinate, actually is directly read from images, use plane calibration target point to make initialization on camera internal parameters, gets $f_c = [f_\alpha, f_\beta]$ initial value and first point, (equal to image center point) pixel position cc definition, inclined coefficient α - c and five distortions coefficient kc initialization (all align 0), from which $f_\alpha = f\alpha, f_\beta = f\beta, \alpha, \beta$ are respectively camera X direction, Y direction two adjacent centers distances, their unit is (mm).

In STEP2, it needs to firstly carry on normalization processing with calibration target calibration point pixel coordinate and parameters after initialization, and then calculate homogeneous matrix A, homogeneous matrix is as formula (6)shows:

$$\mathbf{A} = \begin{bmatrix} \mathbf{e} & \mathbf{0} & \mathbf{c} \\ \mathbf{0} & \mathbf{f} & \mathbf{d} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} \end{bmatrix} \qquad \textbf{(6)}$$

In formula (6), e, f respectively represent every small square lattice four angles points X, Y direction deviation absolute value's average value after affine regularization, c, d respectively represent every square small check X, Y directions average values and e, f product opposite number after affine regularization.

Use iteration method to let pixel re-projection standard deviation to arrive at minimum, by steepest descent method, it updates all known internal and external parameters. Get object initial camera coordinate system coordinate by carrying on coordinate system transformation on initialized internal and external parameters. Objects reference coordinate system to camera coordinate system conversion is as formula (7) shows:

$$\begin{bmatrix} \mathbf{X_c} \\ \mathbf{Y_c} \\ \mathbf{Z_c} \end{bmatrix} = \mathbf{R} \begin{bmatrix} \mathbf{X_W} \\ \mathbf{Y_W} \\ \mathbf{Z_W} \end{bmatrix} + \mathbf{T} \qquad \textbf{(7)}$$

In formula, R is 3×3 rotation matrix T translation vector, use matrix element to express as formula (8)and formula (9)show:

$$\mathbf{R} = \begin{bmatrix} \mathbf{r_1} & \mathbf{r_2} & \mathbf{r_3} \\ \mathbf{r_4} & \mathbf{r_5} & \mathbf{r_6} \\ \mathbf{r_7} & \mathbf{r_8} & \mathbf{r_9} \end{bmatrix} \qquad \textbf{(8)}$$

$$\mathbf{T^T} = \left(\mathbf{t_x} \quad \mathbf{t_y} \quad \mathbf{t_z}\right) \qquad \textbf{(9)}$$

After small hole projection, point coordinate is $P(a,b)$, $a = \dfrac{x}{z}, b = \dfrac{y}{z}$, assume $r^2 = a^2 + b^2$ then distorted projection point is $P_d(x_d, y_d)$. The coordinate point horizontal coordinate value calculates as formula (10), vertical coordinate value calculates as formula (11) :

$$\mathbf{x_d = a(1 + kc(1)r^2 + kc(2)r^4 + kc(5)r^6 + kc(3)ab + kc(4)r^2 + 2a^2)} \quad \textbf{(10)}$$

$$\mathbf{y_d = b(1 + kc(1)r^2 + kc(2)r^4 + kc(5)r^6 + kc(3)(r^2 + 2b^2) + 2kc(4)ab)} \quad \textbf{(11)}$$

Convert into pixel coordinate. Conversion formula is as formula (12) and formula (13)show:

$$\mathbf{x_p = f(1)(x_d + \alpha y_d) + c(1)} \quad \textbf{(12)}$$

$$\mathbf{y_p = f(1)y_d + c(2)} \quad \textbf{(13)}$$

Therefore, the i camera projection process can be expressed as a non-linear function that takes state vector ϕ_i as independent variable, function expression is as formula (14) shows:

$$\mathbf{x^1 = f_1(\phi_i, x^1)} \quad \textbf{(14)}$$

If it can take above points' projection as examples, then it can project arms every articulation point, and connect them into edge line.

Throwing arms three-dimensional model projection formation principles analysis

And in practical operation, we don't do data collection in projected three-dimensional image surfaces, and directly project round dot into two-dimensional images, collect two-dimensional images data, and then get arms model projection some prediction features, as predicted boundary points and so on. Grey features matching is from arms internal each point, and extract image contour and boundary features to match to contour and boundary points. From video results, we can see that discus throwing movement projection has shelters, which needs us to eliminate such projection points that are sheltered when sampling and calculating.

Residual sum of squares is objective function form of Gaussian algorithm, $f(x) = \sum r_i^2(x)$. Set $p = \frac{\partial r}{\partial \phi}$ to be residual vector function $r = [r_1 \quad r_2 \quad \cdots \quad r_n]$ Jacobi matrix, then $f(x)_{\min}$ iteration solving process is as formula (15) shows:

$$\mathbf{x_{n+1} = x_n - (x^t x)^{-1} x^t r(x_n) = x_n + q_n} \quad \textbf{(15)}$$

We define objective function Q as three kinds of features objective functions weighting array as formula (16) shows:

$$\mathbf{Q(\phi_t) = W_1 Q_1 + W_2 Q_2 + W_3 Q_3} \quad \textbf{(16)}$$

In formula (16), Q_1, Q_2, Q_3 respectively represents grey features, contour features and boundary features objective functions.

Assume adjacent two frames images colors are unchanged, their structure on the basis of grey features objective functions are as following :At t moment, $\{x_i^l, i = 1,2,3,\cdots\}$ is arms surface all visible points partial coordinates in the i video camera. Set x_i^t, x_i^{t-1} are arms surface point x_i^l projection coordinates respectively at $[t, t-1]$ time in the i video camera. Let l_t and l_{t-1} to be respectively $[t, t-1]$ the i video camera captured images, we define objective function $Q(\phi_t)$ as formula (17) shows:

$$Q(\phi_t) = \sum_{i=1}^{c} \sum_{j=1}^{n} \left[I_t\left(x_i^t\right) - I_{t-1}\left(x_i^{t-1}\right) \right]_i^2 \quad (17)$$

Therefore, it can get arms reconstruction figure when throwing discus, it provides a scientific and effective training and observation ways for sports researchers and discus throwing event coaches.

CONCLUSION

The paper firstly analyzes discus throwing event basic technical movements, states discus throwing process human body movement postures, focuses on researching on throwing arms trajectory features in rotation process and discus force status, which provides orientations for discus throwing competitions distance maximization pursuing, and also builds basis for throwing arms rotation process two-dimensional images three-dimensional reconstruction. In the paper, it states two-dimensional image three-dimensional reconstruction process principle basis that is firstly getting rotational arms projections in three planes after three-dimensional reconstruction, and then applying projection and physical objects relations to get three-dimensional reconstruction final model. After summarizing video tracking technology's human skeleton shape extraction and articulation point extraction methods, it provides video camera articulation points calibration methods, by video camera obtained two-dimensional images after calibration, it calculates three planes projection and provides scientific algorithm for final three-dimensional reconstruction.

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