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Article

Integration of biomechanics and IoT in physical dance sports: Enhancing campus culture and psychological development in higher education

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Abstract: Sports dance, a sport that combines art and competition, has steadily taken center stage in university physical education programs in recent years. This study examines the complex relationship between sports dancing, campus culture, and college students' psychological development using digital twin technologies and the Internet of Things (IoT). In order to provide a thorough investigation of the physical movement features involved in sports dance, the emphasis is on introducing a biomechanical perspective. A connected model of the biomechanical properties and psychological development aspects of sports dance movements was built, and a hierarchical nearest neighbor propagation approach was suggested for multi-level pose clustering of sports dance motions. It was discovered through experimental validation that the digital twin-based dance scene design greatly increased dance motion capture accuracy and optimized the virtual digital scene for motion recovery. According to the study's findings, biomechanical data analysis powered by digital twins can more effectively describe the kinematic and dynamic properties of dance moves and raise the level of scientificity in dance movement instruction and performance. Furthermore, the model's stability is demonstrated by the optimized model's split half reliability coefficient of 0.889 and internal consistency coefficient of 0.887. This study offers a novel method for the theoretical investigation and real-world implementation of sports dance instruction in higher education by fusing biomechanics and digital technology, which supports the enhancement of students' mental and physical well-being.

Keywords: biomechanics; Internet of Things; digital twin; sport dance; campus culture

1. Introduction

Sports dance, as a unique fusion of physical exercise and artistic expression, has become an increasingly prominent part of university physical education [1,2]. Characterized by its vibrant diversity and competitive spirit, sports dance spans social dances like the cha-cha and rumba, and competitive styles such as Latin and modern ballroom dances. These dynamic activities have found their way into educational curricula not only for their physical benefits but also for their cultural and psychological contributions to students' development [3,4]. However, the precise and technical nature of sports dance demands a more scientific approach to its training and analysis [5].

Existing research on sports dance has made significant progress in biomechanical analysis and psychological development, but certain limitations remain [6]. For instance, studies often focus on either the physical aspects, such as posture and balance, or the psychological aspects, such as emotional intelligence and self-confidence, without adequately exploring the coupling relationship between the two domains [7,8]. Additionally, the integration of cutting-edge technologies like the Internet of Things (IoT) and digital twins in sports dance training has yet to receive comprehensive attention. These gaps call for an interdisciplinary approach that bridges biomechanics and psychology to develop a deeper understanding of how these factors interact.

2. Model of physical dance sports based on digital twin

To create a digital twin-based coupling model of physical dance sport and university campus culture, we must first extract the important model coordinate points. The two distinct sites here are physical dancing sport and college culture, and the crucial node of model coupling is the mathematical logic that comes before these two sites [9,10].

Each target in two nearby stations of the sport dance movement is first modelled, along with the coordinates, before the model is aligned. The target pairs are then used to solve the seven conversion parameters needed for the alignment of the two nearby stations, after which the two nearby stations are rotated and scaled according to the converted conversion parameters to complete the point cloud alignment. The process of solving for the 7 parameters is as follows: one of the target pairs is the point in the reference station with coordinates $A'(x', y', z')$ and the other is the point in the station to be matched with coordinates $A(x, y, z)$, then we can obtain the Equation (1).

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} \tag{1}$$

where: $t_i (i = 1,2,3)$ is the translation parameter, $r_i j (i = 1,2,3; j = 1,2,3)$ is the rotation matrix, because the point cloud data is not scaled in the acquisition process, which is a rigid transformation, so we can define the rotation factor of sports dance movement is 1, and get the Equation (2) as:

$$\begin{bmatrix} \cos\beta\cos\gamma & \cos\beta\sin\gamma & \sin\beta \\ -\cos\alpha\sin\gamma - \sin\alpha\sin\beta\cos\gamma & \cos\alpha\cos\gamma - \sin\alpha\sin\beta\sin\gamma & \sin\alpha\cos\beta \\ \sin\alpha\sin\gamma - \cos\alpha\sin\beta\cos\gamma & -\sin\alpha\cos\gamma - \cos\alpha\sin\beta\sin\gamma & \cos\alpha\cos\beta \end{bmatrix} \tag{2}$$

where, α, β, γ is the rotation angle of the 3D laser scanner's own coordinate system around x, y, z axis respectively; t_1, t_2, t_3 and α, β, γ are the translation distance and rotation angle around x, y, z axis needed to align the point cloud to convert the point cloud data.

In the three-dimensional space of sports dance movement, the transformation of points can be represented mathematically by multiplying the flush coordinates of the points with the three-dimensional transformation matrix of the fourth order. The initial point position qi (x, y, z) needs to be represented by (x, y, z, 1), according to the principle of graphical transformation then there exists a fourth-order coordinate transformation matrix n_4 such that $qj = qin_4$, the matrix coupling Equations (3)–(5) of the sports dance sports site and the campus culture site can be obtained.

$$(x', \quad y', \quad z', \quad 1) = (x, \quad y, \quad z, \quad 1) \begin{bmatrix} a_{11} & a_{12} & a_{13} & p_x \\ a_{21} & a_{22} & a_{23} & p_y \\ a_{31} & a_{32} & a_{33} & p_z \\ d_x & d_y & d_z & s \end{bmatrix} \tag{3}$$

$$M_1 = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad (4)$$

$$M_2 = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} \quad (5)$$

In this model, the fourth-order coordinate transformation matrix n_4 can be divided into 4 parts according to its significance for the changes, where as shown in Equations (6) and (7).

$$M_3 = [d_x \quad d_y \quad d_z] \quad (6)$$

$$M_4 = [s] \quad (7)$$

To execute local scale transformation, symmetry transformation, rotation transformation, and tangent transformation of the points, M_1 denotes the three-dimensional linear transformation matrix. The perspective projection transformation matrix, designated as M_2, is used to transform the points' perspective [11,12]. The translation transformation matrix, designated by the letter M_3, is used to translate the points. The entire scale transformation matrix, or M_4, is what's employed to scale-transform the points. The translation transformation matrix is as in Equation (8) if the object under investigation is moved a specific distance in the *x*, *y*, and *z* directions without changing the object's size or shape.

$$q_j = [x, \quad y, \quad z, \quad 1]\, M_m = [x, \quad y, \quad z, \quad 1] \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ d_x & d_y & d_z & 1 \end{bmatrix} = [x + dx, y + dy, z + dz, 1] \quad (8)$$

If the physical dance movement model scale transformation is divided into local scale transformation and overall scale transformation, the transformation matrix is as in Equation (9).

$$q_j = [x, \quad y, \quad z, \quad 1]\, M_s = [x, \quad y, \quad z, \quad 1] \begin{bmatrix} a & 0 & 0 & 0 \\ 0 & b & 0 & 0 \\ 0 & 0 & c & 0 \\ 0 & 0 & 0 & s \end{bmatrix} = [a_x, \quad b_y, \quad c_z, \quad s] \quad (9)$$

When $a = b = c = 1$ and s is any value, Equation (10) represents the overall ratio transformation; when $s = 1$ and a, b and c are any values, Equation (11) represents the local ratio transformation.

$$\begin{aligned} q_j = [x, \quad y, \quad z, \quad 1]Rz = [x, \quad y, \quad z, \quad 1] &\begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \\ = [x\cos\theta - y\sin\theta, \quad x\sin\theta + y\cos\theta, \quad z, \quad 1] \end{aligned} \quad (10)$$

$$q_j = [x, \quad y, \quad z, \quad 1]R_x = [x, \quad y, \quad z, \quad 1]\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = [x, \quad y\cos\theta - z\sin\theta, \quad y\sin\theta + z\cos\theta, \quad 1] \tag{11}$$

These theoretical underpinnings serve as the basis for the coupling analysis between the dynamic movement model and campus culture in the digital twin system of sports dance movement. As illustrated in **Figure 1**, from there, calculations are made based on the driving data to complete the synchronisation of the model movement to achieve the virtual and real states under the real-time data drive [13].

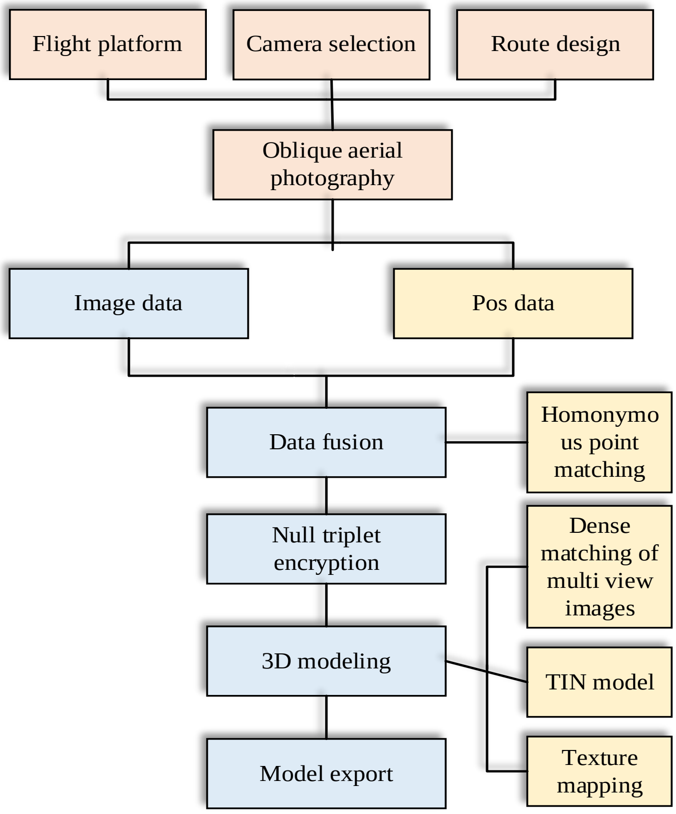

Figure 1. Synchronous paradigm of sports dance.

Then, a dense point cloud is computed using the sports dance motion synchronization paradigm and known information about the internal and external orientation elements. In the PMVS algorithm, the point cloud is represented as a surface slice, which is a plane approximately tangent to the surface of the reconstructed object, represented by the center coordinates $C(p)$ and the unit normal vector $\vec{n}(p)$, and its vector direction points to the corresponding camera optical center. The PMVS algorithm adopted in this model first uses the Harris operator for feature point extraction, and the Harris corner point extraction operator performs corner point extraction by means of the autocorrelation matrix M, the M matrix is defined in Equation (12).

$$M = G(\tilde{n}) \otimes \begin{bmatrix} g_x & g_x g_y \\ g_y g_x & g_y \end{bmatrix} \tag{12}$$

The decision is made to use images with angles less than 60 degrees as the search image. Candidate matching points in the search image, corresponding to the feature points on the reference image, are identified. Using the *P*-matrix equation, the corresponding model points for each pair of identical points are located. The calculation of the *P*-matrix involves solving the exterior orientation parameters and camera parameters, which are necessary to establish the object-side and image-side coordinate transformation matrices [14].

The model point serves as the initial reference point for the facet and is treated as its center. The center coordinates and normal vector of the facet slice are optimized using the conjugate gradient method to achieve a more precise match. Subsequently, the displayed image is refreshed. A facet is considered correctly matched if it appears in more than three visible images [15].

To identify the image's corresponding image point, the object point is projected onto the image plane. As illustrated in **Figure 2**, this model can determine the multivariate coupling relationship between physical dance sports and campus culture. Correctly matched object points are then used as seeds for subsequent coupling analyses, ensuring a robust foundation for further investigations.

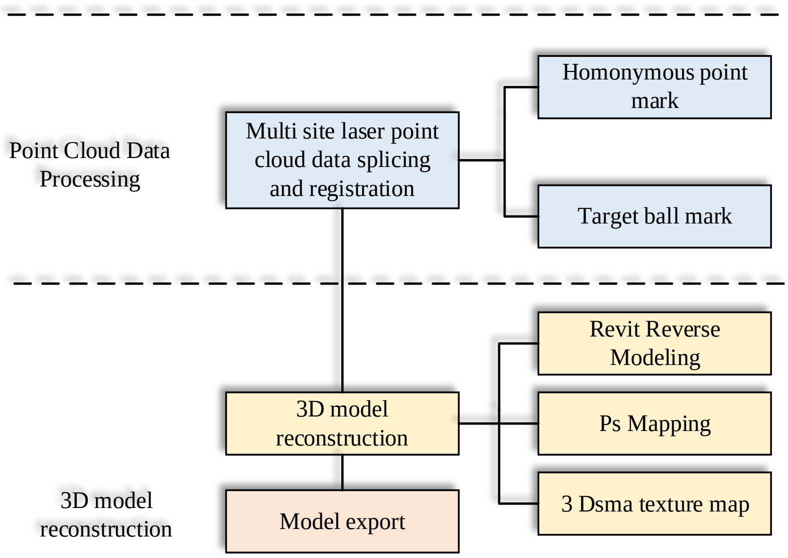

Figure 2. Judgment criteria for the multiple coupling relationship between sports dance and campus culture.

3. Methods

3.1. Dataset construction and data pre-processing

In September 2021, the first semester of the new academic year, the experiment for Data Set A was carried out. The experiment lasted 12 weeks, with the first and last week serving as the test week and the middle 10 weeks serving as the experimental teaching week. The following was a general breakdown of the 35-min sessions: (3) 25 min for the physical dance (10 min for the physical training and 15 min for the physical dance); (1) 5 min for the beginning part, mostly for the formation and preparation activities; (2) 25 min for the physical dance; and (3) 5 min for the conclusion portion, mostly for the presentation and summary of what was learned. The three levels' control classes adhere to the school's standard physical education curriculum. For pupils in grades 1 to 2, level 1 teaches the jitterbug (sailor dance), cha-cha-cha, basic ballet hand and foot postures, and arm wave combinations. Level 2 students study fundamental dance steps, Latin cha-cha-cha, and cowboy dance in sections 3 to 4. Level 3 is where students learn Latin dance and the fundamentals of ballet. The physical education dance class schedule for grades 1 to 2 is based on the four curriculum criteria, as stated in **Table 1**.

Table 1. Data collection content of dataset A.

Week	Basic dance training	Sport Dance
Week 1	Ballet hand position combination	Queue Exercise 1
	Ballet foot position combination	Queue Exercise 2
Week 2	Play Barre's hand position with music	Rumba rhythm
	Close music ballet hand position and foot position combination	Rumba moving left and right
Week 3	Arm wave combination 1	Review the basic steps
	Arm wave combination 2	Rumba square
Week 4	Arm wave combination 3	Rumba moves forward and backward
	Arm wave combination 4	Lombar fixed point turn
Week 5	Review arm combination 1~4	Review the basic steps
	Review lesson (music)	Game to practice reaction speed
Week 6	Sports dance theory class (watch sports dance related videos)	
	Physical fitness test	
Week 7	Arm wave combination 5	Chacha just moves
	Arm wave combination 6	Chacha just moves left and right
Week 8	Review arm wave combination 1–6	Review + Chacha
Week 9	Floor wiping combination 1	Review the basic steps learned by Cha Cha with music
	Floor wiping combination 2	Chacha just goes forward and backward
	Floor wiping combination 3	Cha Cha just stepped forward
Week 10	Review floor wiping combination 1–3	Review all the basic steps of Chacha
	Review (hand position, foot position, arm wave, scrubbing) combination	All the basic steps of the double dance Chacha

Additionally, Data Set B was described as the physical education dance curriculum for pupils in grades three to four, with a small upgrade from Level 1 to include the Latin-influenced elements of the cha-cha-cha and the cowboy. based on **Table 2**. The classes in Dataset B, shown in **Table 2**, are intended to help third- and fourth-grade kids improve their dance skills while including more Latin dance elements (such as jive and cha-cha). From a biomechanical point of view, the body must have complex dynamic properties and work well in terms of center of gravity transfer, movement stability, and movement efficiency. A biomechanical analysis of the teaching resources is shown in **Table 2**. Students primarily use the shoulder and elbow joints' flexion, extension, and rotation when learning arm wave combinations. Power must be progressively transferred through the synchronized movement of the upper limbs before being released to the fingers in order for the wave movement to occur. The stability of the scapula and the regulation of the elbow joint rotation axis determine how well this wave transmission works. Students can improve arm flexibility and lessen shoulder muscle strain brought on by regular use by engaging in high-frequency exercise [16].

Table 2. Data collection content of dataset B.

Week	Basic dance training	Sport Dance
Week 1	Ballet hand position combination	Chacha just moves
	Ballet foot position combination	Chacha just moves left and right
Week 2	Play Barre's hand position with music	Review + Chacha
	Close music ballet hand position and foot position combination	Review the basic steps learned by Cha Cha with music
Week 3	Arm wave combination 1	Chacha just goes forward and backward
	Arm wave combination 2	Cha Cha just stepped forward
Week 4	Arm wave combination 3	Chacha New York Step
	Arm wave combination 4	Chacha is holding hands
Week 5	Review arm combination 1~4	Review all the basic steps of Chacha
	Review lesson (music)	Practice in pairs
Week 6	Sports dance theory class (watch sports dance related videos)	
	Physical fitness test	
Week 7	Arm wave combination 5	Cowboy dance rhythm
	Arm wave combination 6	Mountaineering step
Week 8	Review arm wave combination 1–6	Cowboy Kick Practice
Week 9	Floor wiping combination 1	Cowboy moves left and right
	Floor wiping combination 2	Cowboys move forward and backward
	Floor wiping combination 3	Review the basics of denim
Week 10	Review floor wiping combination 1–3	Review the basic steps of Chacha and cowboy
	Review (hand position, foot position, arm wave, scrubbing) combination	All the basic steps of two people dancing together in Chacha and cowboy

To swiftly finish the center of gravity shift in the cha-cha beat, pupils must constantly alter the support point between their toes and heels. The ankle joint's range of motion and the involvement of the lower limb muscle groups—particularly the gastrocnemius and soleus—are essential to this process. In addition to increasing movement fluidity, effective center of gravity control lowers the chance of falling because of the center of gravity change.

For example, in the "New York Step" and "holding hands" of the cha-cha, students have to keep their upper body stable while rapidly rotating. Core strength, which includes the rectus abdominis and oblique abdominal muscles, is the key to achieving this goal. Dynamic core training, such using a balancing board, can help students further develop their core control and, in turn, enhance their dancing ability.

Dataset C consists of physical dance learning content designed for students in grades 5–6, focusing on Latin dance genres such as the cowboy and samba, with an emphasis on developing intricate movement patterns and powerful expressions. As detailed in **Table 3**, the dances included in this dataset, such as jive and samba, require students to demonstrate significant coordination, muscular strength, and joint flexibility from a biomechanical perspective.

The cowboy dance, featuring steps like the "Mountaineering step" and "Cowboy Kick Practice," demands exceptional dynamic knee stability. These exercises require students to carefully coordinate their quadriceps and hamstrings to maintain knee joint stability during lower limb movements. This training significantly enhances lower limb explosive power and movement coordination [17].

In contrast, samba dance emphasizes fluid motion and rapid bouncing. Its defining "fast rhythmic movement" requires students to quickly complete continuous bouncing motions by harnessing the elastic energy of their ankle and knee joints. This movement pattern demands highly efficient energy storage and release from these joints. Dynamic biomechanical analysis can be used to assess the capacity of students' ankle joints to store and release energy during bouncing, allowing for tailored training plans to optimize performance.

Table 3. Data collection content of dataset C.

Week	Basic dance training	Sport Dance
Week 1	Ballet hand position combination	Samba crotch drill
	Ballet foot position combination	Samba moves forward and backward
Week 2	Play Barre's hand position with music	Samba basic moving steps
	Close music ballet hand position and foot position combination	Music practice + cooperation
Week 3	Arm wave combination 1	Samba left and right fork step
	Arm wave combination 2	Botafogo
Week 4	Arm wave combination 3	Music practice + cooperation
	Arm wave combination 4	Waltz Swing Practice
Week 5	Review arm combination 1~4	Waltz square
	Review lesson (music)	Practice in pairs
Week 6	Sports dance theory class (watch sports dance related videos)	
	Physical fitness test	
Week 7	Arm wave combination 5	Waltz combo
	Arm wave combination 6	Review the waltz
Week 8	Review arm wave combination 1-6	Chacha just moves
Week 9	Floor wiping combination 1	Chacha just moves left and right
	Floor wiping combination 2	Chacha is just square
	Floor wiping combination 3	Chacha just moves forward and backward
Week 10	Review floor wiping combination 1–3	Review together Cha Cha Cha
	Review (hand position, foot position, arm wave, scrubbing) combination	Review the basic steps learned

Samba training requires trainees to blend upper body twisting with lower limb footwork, such as "Cowboys move left and right" and "Cowboys move forward and backward.” The flexibility of the hip joints and lumbar spine are key components of this whole-body coordination training. Students’ movement trajectories during training can be tracked in real time to optimize their movement patterns using motion capture technologies and digital twin systems.

Prior to the trial, the experimental class’s parents and teachers were questioned using questionnaires, and the physical fitness and adolescent mental health assessment scales of the students in the experimental and control classes were measured [18]. The 12-week total experimental period was split into 10 weeks of experimental training and 1 week each for the pre- and post-tests. I delivered each questionnaire and scale for the pre-test and post-test, respectively. I spent 10 weeks instructing Level 1, Level 2, and Level 3 in the experimental class. The students in the control class were taught in the normal physical education program of the school.

Additionally, before the experiment, the pre-test psychological scale was given out, and it was filled out in the teacher’s presence. The post-test psychological scale was filled out during the final class. This questionnaire was not sent out following the experiment because “Questionnaire 1” was utilised for the pre-survey. There were 118 questionnaires issued both before and after the experiment, and both their return rate and efficiency rate were 100% (as shown in **Tables 4** and **5**).

Table 4. Statistics of questionnaire distribution and recovery before the experiment.

Questionnaire	Number of distributions	Recycled quantity	Rate of recovery	Effective number	Effective
Questionnaire1	118	118	100%	118	100%
Questionnaire2	118	118	100%	118	100%
Questionnaire3	118	118	100%	118	100%

Table 5. Statistical table of questionnaire distribution and recovery after the experiment.

Questionnaire	Number of distributions	Recycled quantity	Rate of recovery	Effective number	Effective
Questionnaire1	118	118	100%	118	100%
Questionnaire2	118	118	100%	118	100%

3.2. Multiple coupling model operation and optimization

Data-driven design, login verification design, scene recovery design, roaming function design, environment immersion design (by adding the design of scene sound effects to enhance the user’s immersion, make the digital twin scene more realistic), and environment immersion design are the main requirements for creating a digital twin for the coupling monitoring in the sports dance sports campus gymnasium environment. In order to preserve consistency, it primarily serves to ensure that each piece of data in the digital twin world is derived from actual data in the physical world. **Figure 3** displays the real-time visualisation system’s functional design:

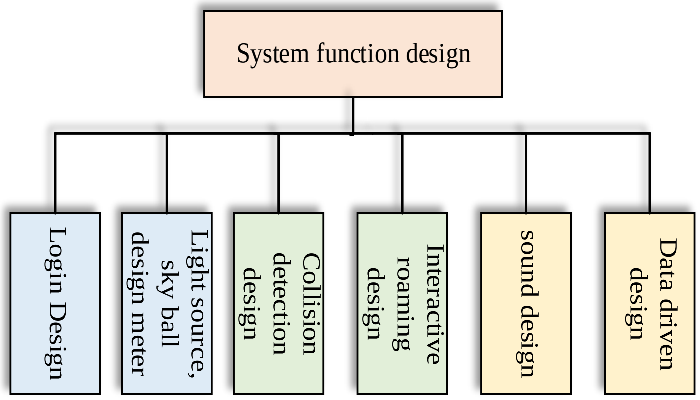

Figure 3. Functional design of real-time visualization system for sports dance multi coupling model.

Figure 3 shows the functional design of the real-time visualization system for the multi coupling model of sports dance. This design aims to create an immersive data-driven digital twin for campus sports dance activities, specifically targeting the sports dance course environment in the gymnasium.

The key components of system design include:

1) Data driven design: This section ensures that digital twins accurately represent the real world and integrate actual data from physical space. By ensuring consistency between the digital world and the physical world, the digital twin environment can reflect the real-time status of the sports arena and its activities.
2) Login verification design: This feature ensures the security of the system by verifying the user's identity information. Only authorized users (such as teachers or students) can enter the digital twin environment, ensuring privacy and data security.
3) Scene recovery design: This design enables the system to restore the digital twin environment to its previous state, allowing users to review past scenes, events, or training processes. This feature ensures the continuity of monitoring and analysis during sports dance training.
4) Roaming function design: Roaming function allows users to freely navigate in the digital twin environment, providing a sense of spatial exploration. Users can virtually move freely within the sports arena, observe different areas, and access real-time data from multiple perspectives.
5) Immersive Environment Design: In order to enhance the user experience, scene sound effects have been added to the design, making the digital twin environment more realistic and immersive. This design element aims to reproduce common sounds in the sports arena, such as music and footsteps, in order to enhance the user's presence.

Users must provide pre-set account information to complete the system login in **Figure 4**, which depicts the flowchart of sports dance movement multi-coupling model verification. The basis of user verification is the comparison of the user's account and password information with the user data kept in the system database. If the system database can match the pertinent user information, a successful login dialogue prompt will appear, and you can then log in; if not, an error prompt will appear, and you'll have to input your account and password again. By logging into this system and coupling calibration by mental scale, students can synchronise the state pattern of physical dance practise.

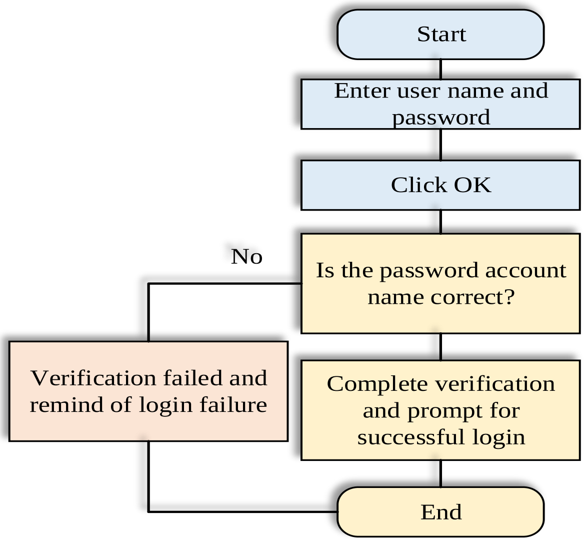

Figure 4. Login verification flow chart of sports dance multi coupling model.

The environment, structures, and people have been given coupling components that give the digital twin system for tracking dance and sport movement on campus a roving view. For instance, this design uses a box coupler for the ground, a capsule coupler for the trees' trunks and crowns, and a sphere coupler for the character model. These couplers can ensure the coupling effect and make the coupling calculation simpler to speed up rendering. All models in the scene are given the appropriate couplers according to their needs.

The data gathering process and the presentation process of the digital twin system are kept apart by using the database as an intermediary step for data coupling. This improves system isolation, reduces coupling, and makes it easier to expand the system after adding more devices. **Figure 5** illustrates how to set up a specific thread in the digital twin system for a direct device connection to collect device data.

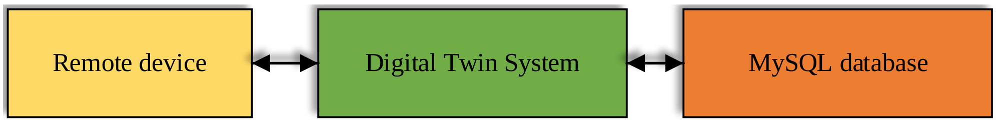

Figure 5. Data acquisition method of opening dedicated thread.

The digital twin system links to the remote device using a dedicated thread to read the device information when it obtains sports dance sports reality data. The driver function of the digital twin sports dancing sports virtual device receives the read device information after which it writes it to a MySQL database for persistent storage. Comparing the two data acquisition methods, this research opts to use the database as an intermediary data gathering method, as shown in **Figure 6**. The digital acquisition client establishes a connection with the remote device, transmits real-time device information to the MySQL database, and retrieves real device operating data for the digital twin system. Although the data collecting approach in **Figure 7** can produce the same results, it is not scalable with the addition of new devices and is not well-suited for future growth. In order to increase the system's scalability, the database is finally selected as the data collecting technique for the intermediate step.

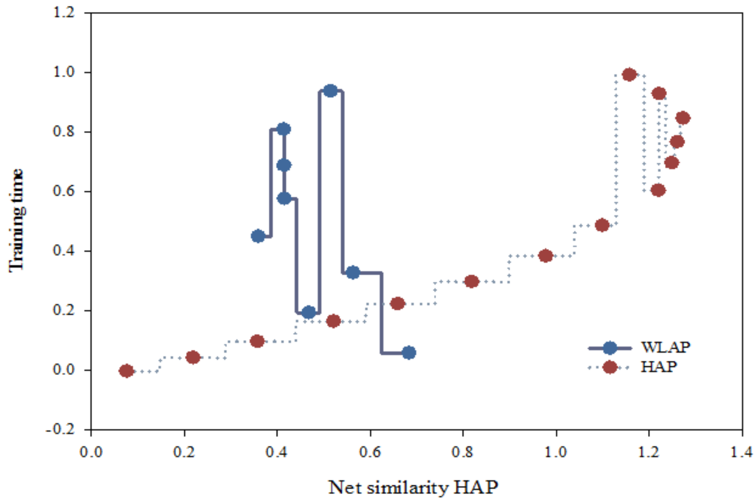

Figure 6. Similarity comparison of sports dance multiple coupling models.

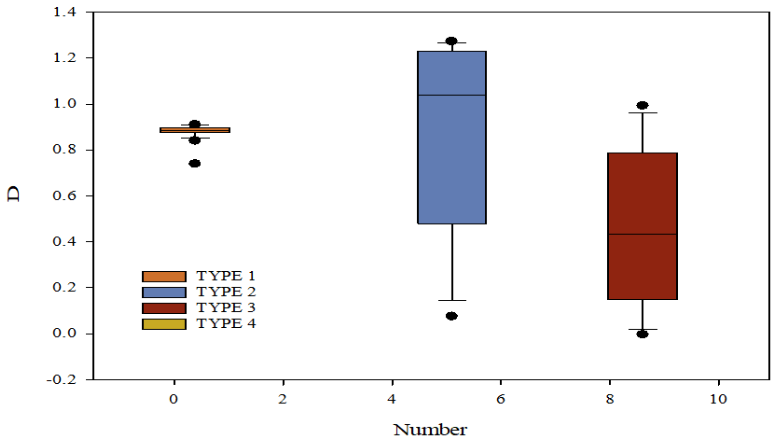

Figure 7. Average distance difference of different paths in sports dance multi coupling model.

4. Experiment

4.1. Model reliability test

To ensure the validity and rationality of the questionnaire, the validity of the content of Data Set A, Data Set B and Data Set C in the study was verified by the model. The questionnaire was evaluated and checked with a five-level evaluation method, and the designed questionnaire can be used as a survey tool for the study and used for research analysis, as shown in **Table 6**.

Table 6. Data set validity evaluation table ($N = 8$).

Evaluation items	Statistical method	Evaluation degree				
		Very reasonable	**Relatively reasonable**	**commonly**	**Not very reasonable**	**Very unreasonable**
Content design	Frequency	5	2	1	0	0
	Percent%	62.50	37.50	12.50	0	0
Structural design	Frequency	3	4	1	0	0
	Percent%	37.50	50.00	12.50	0	0

The Student Psychological Characteristics Scale demonstrates strong content validity and structural validity, as confirmed through validation factor analysis. The NFI, NNFI, RFI, and CGI values for the scale's dimensions are all greater than 0.90, while the RMSEA value is below 0.1, indicating good model fit. Additionally, the scale exhibits strong association validity. With 27 items spanning six dimensions, this scale is utilized to study the impact of physical dance sports on both college campus culture and students' psychological development.

In the study, we use the objective function defined in Equation (7) to compare the performance of three algorithms—HAP, MLAPW, and MLKMeans—on a multivariate coupled model of physical dance sports. The analysis includes four levels, with preference degrees generated based on the heuristics proposed for the AP method, which are then linearized using logarithms. To conduct the comparison, 1274 preference options are randomly generated within this range.

For the MLKMeans algorithm, the number of clusters per layer is set to match the number of clusters generated by HAP, ensuring that both the HAP and MLKMeans algorithms have an equal number of clusters at each layer. This alignment allows for a meaningful comparison of network similarity between the two algorithms. **Figure 6** illustrates the network generated by each configuration of HAP, MLAPW, and MLKMeans, with the results of the similarity comparison also presented.

Figure 7 shows that in virtually all settings, HAP is able to outperform MLAPW and MLKMeans. Despite the fact that both MLAP and MLKMeans are greedy algorithms, when clustering at higher levels, the optimal solution obtained at the bottom level will become the suboptimal solution rather than the global optimal solution. This is mainly because MLAP and MLKMeans lack the global optimisation objective and, as a result, lack the synchronous information exchange between the bottom level and the top level during the clustering process. Instead, by exchanging information between various levels and moving information between upper and lower levels, HAP with a global optimisation objective can identify all points as potential representative points at various clustering levels. In comparison to MLAP and MLKMeans, which are capable of more effective data abstraction, HAP can produce superior global optimisation outcomes in this approach.

By combining various distance measures on the top and second uppermost levels of the data abstraction, **Figure 8** depicts the distances between the Phylogenetic Trees and GroundTruth. It is clear that the phylogenetic tree produced using the combination of two distance measurements has a far higher quality than the one produced using the individual distance metrics. The quality of the SSTs generated with the combination of 3 distance measures and 4 distance measures is also improved, but the quality of the SSTs generated with the combination of 3 distance measures and 4 distance measures is very similar, indicating that the quality of the SSTs won't be significantly affected by the increase in distance measures used in the computation after a certain point. In the tests that follow, we contrast the Phylogenetic Tree created by combining the four distance metrics J2JD, J2PD, B2BAW, and B2PA with other approaches.

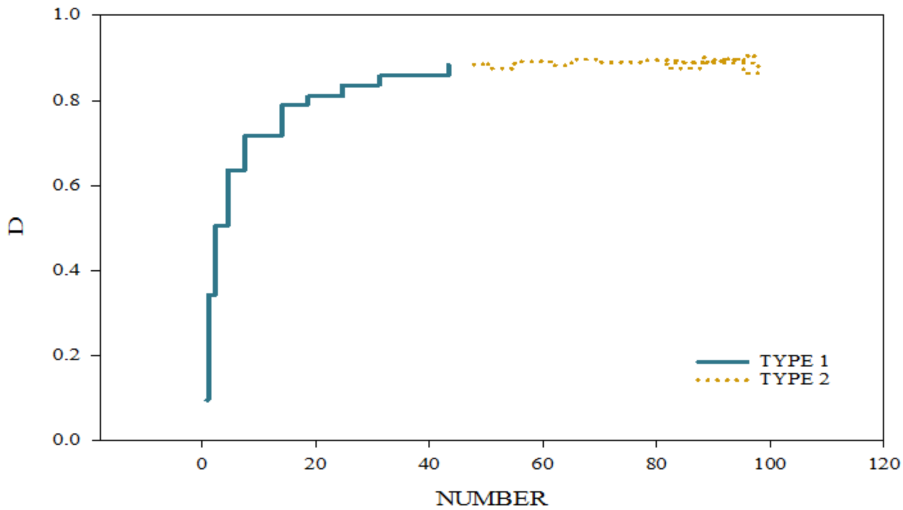

Figure 8. Average distance difference of different paths in the multi coupling model of sports dance after optimization.

4.2. Empirical effects of physical dance sports

We evaluated the mental health of the three groups—A, B, and C—as well as carried out independent sample tests—in order to determine the model's empirical level. As indicated in **Tables 7** and **8**, it was discovered that there was no significant variation in the experimental subjects' mental health between the various data sets prior to the empirical test ($P > 0.05$). Additionally, study has revealed some differences between the experimental group's and control group's mental health.

Table 7. Impact value of sports dance on students' psychological growth (dataset A).

Dimension	**Pre test of Guangzhou Institute of Physical Education**	**Pre test of Guangdong Light Industry Vocational and Technical College**	***t***	***p***
	***M* ± SD**	***M* ± SD**		
Happiness experience	16.82 ± 39.4	16.89 ± 3.10	−0.127	0.899
Interpersonal harmony	16.86 ± 2.68	16.54 ± 2.85	0.618	0.538
Actively enjoy learning	15.90 ± 3.67	15.09 ± 3.61	1.192	0.236
Emotional regulation	13.51 ± 3.57	12.26 ± 3.52	1.883	0.062
Goal pursuit	13.84 ± 2.61	12.78 ± 3.19	1.922	0.057
Dare to challenge	14.29 ± 2.63	13.52 ± 2.13	1.742	0.084

Table 8. Impact value of sports dance on students' psychological growth (dataset B).

Dimension	Pre test of Guangzhou Institute of Physical Education	Pre test of Guangdong Light Industry Vocational and Technical College	*t*	*p*
	M **± SD**	***M*** **± SD**		
Nervous	6.49 ± 3.28	6.55 ± 2.60	−0.112	0.911
Anger	6.22 ± 3.82	6.39 ± 3.72	−0.237	0.813
Fatigue	5.88 ± 2.84	5.01 ± 2.10	1.899	0.060
Depressed	5.79 ± 3.35	5.37 ± 2.72	0.748	0.456
Energy	10.92 ± 3.79	10.09 ± 2.96	1.337	0.184
Panic	4.80 ± 2.46	4.42 ± 2.31	0.848	0.398
Self-esteem	7.50 ± 2.53	8.20 ± 2.46	−1.533	0.128
Negative emotions	29.18 ± 11.40	27.75 ± 10.03	0.721	0.472
Positive emotions	18.41 ± 5.51	18.29 ± 4.47	0.128	0.898
TMD	110.78 ± 13.71	109.46 ± 10.44	0.590	0.556

The accuracy, stability, and dynamic balance of movements may play a part in assessing students' psychological development in terms of happiness, emotional regulation, learning enthusiasm, and challenging spirit. Biomechanics offers a fresh viewpoint for the study of the psychological effects of sports dance. The function of biomechanics in fostering mental wellness is investigated by combining the dimensions of **Tables 7** and **8**.

Table 7 shows a strong correlation between the development of happiness and the fluidity of dancers' bodily motions. Students must learn to manage limb coherence in dynamic processes including arm waves, foot motions, and weight shifts through dance practice. This fluency is linked to the development of muscle memory and the improvement of motor nerve control in biomechanical study. The cerebellum and primary motor cortex of the brain gradually optimize the movement path as pupils perform intricate dance steps on a regular basis, making the movement more fluid and efficient. This development raises pupils' feelings of enjoyment as well as their sense of control over their own actions.

The stability of posture and the strengthening of the core muscles during dance may be the cause of improved emotional regulation. Stable core strength is crucial for maintaining proper posture and lowering psychological stress, according to biomechanical study. For instance, the stability of the core muscles helps trainees overcome vertigo and improves control and confidence when performing the rotation in the cha-cha dance. Emotional regulation skills can be improved and unpleasant emotions can be effectively reduced by this psychological sense of security created by physical control.

Students' progressive mastery of dancing techniques serves as incentive for pursuing goals. Biomechanics offers a scientific foundation for action breakdown and movement optimization in sports dancing. For instance, in order to preserve balance and coordination when learning fundamental dance moves (such square steps and basic turns), students must carefully regulate the angles of their ankle, knee, and hip joints. Students gain a clear knowledge of their objectives and the capacity to carry them out by progressively overcoming these technical obstacles, which increases their psychological bravery in setting and pursuing goals.

Table 8 shows that the improvement of the sense of control over the body and the skill of movement patterns may be linked to the reduction of tension. Enhancing movement proficiency has been shown in biomechanical study to lessen psychological stress. For instance, pupils must synchronize the swing of their upper and lower limbs when practicing the rhythms of cowboy dancing. The neuromuscular system progressively becomes accustomed to these intricate motions through repeated repetition, which lessens psychological tension and movement ambiguity.

The primary causes of fatigue are excessive muscular control and high energy expenditure during movements. Through biomechanical analysis, it is possible to optimize the line of center of gravity transfer and minimize needless limb swings, among other aspects of students' dance movement efficiency. Students must utilize their joints' suppleness to store and release energy, particularly in the fast-paced samba and cowboy dances, in order to minimize energy waste. In addition to lowering physical energy expenditure, this enhancement aids pupils in developing more sustained expressiveness, which lessens psychological exhaustion.

Students' good feelings are immediately enhanced when dynamic equilibrium is established in dance movements. According to biomechanics, the hip joint must precisely manage the center of gravity and distribute plantar pressure uniformly in order to achieve dynamic equilibrium. For instance, pupils demonstrate confidence and vigor while maintaining balance by rapidly switching support points during the bouncing movements of samba dance. In addition to increasing students' enthusiasm for dance, this capacity to manage dynamic balance also improves their pleasant emotional experiences on a psychological level.

Students who receive dance coordination training might improve their psychological focus and self-assurance, which can help them deal with negative emotions. For instance, pupils must highly coordinate their movements and rhythms with one another during pair dance instruction. Building trust with others and with oneself is facilitated by this cooperative relationship. Couple dancing training also incorporates vestibular sense and tactile feedback from a biomechanical standpoint. Students' psychological stability is further improved by this multisensory integration.

When paired with biomechanical analysis, the shifts in psychological dimensions displayed in **Tables 7** and **8** provide a clearer understanding of how sports dancing fosters psychological development. Enhancing core strength, dynamic balance, body control, and movement routes, among other things, not only enhances students' physiological athletic performance but also their psychological well-being, ability to pursue goals, and happiness. Together with biomechanics, this viewpoint offers scientific backing for upcoming sports dance instruction and psychological interventions. It also establishes the groundwork for creating more effective lesson plans.

5. Conclusion

Physical dance activities play a vital role in helping college students manage their emotions, foster interpersonal relationships, build resilience to tackle challenges, and actively support mental health by promoting positive personality traits. Drawing on this context, the present study develops a multi-coupling model for physical dance sports based on the integration of Internet of Things (IoT) technology and digital twin concepts, focusing on campus culture and student psychology.

The proposed approach employs a hierarchical nearest neighbor propagation algorithm rooted in quantitative analysis to achieve multilayer gesture clustering. The results of data abstraction reveal a clear progression from detailed observations to higher-level abstractions, aligning seamlessly with the cognitive processing stages of students.

The measurement outcomes align with general theoretical assumptions and are further validated by experimental data. The model demonstrates robust accuracy and reliability, with an internal consistency coefficient of 0.887 and a split-half reliability coefficient of 0.889, both significantly exceeding the threshold of 0.585. These findings underscore the model's credibility in analyzing the two coupling loci of campus culture and student psychology.

Empirical evidence further suggests that physical dance activities serve as an effective intervention for addressing emotional challenges among college students, significantly enhancing their assimilation into campus culture.

Ethical approval: Not applicable.

Data availability: The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflict of interest: The author declares no conflict of interest.

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