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Research Article

TSN: Performance Creative Choreography Based on Twin Sensor Network

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The purpose of this paper is to improve the efficiency of performance creative choreography (PCC). Our research work shows that we can realize the model integration and data optimization for PCC in complex environments based on the combined architecture of sensor network (SN) and machine-learning algorithm (MLA). In order to explain the process and content of this research better, this paper designs a specific problem description framework for PCC, which mainly includes the following content: (1) a twin sensor network (TSN) architecture based on digital twin information interaction is proposed, which defines and describes the acquisition method, classification (creative data, rehearsal data, and live data), and temporal and spatial features of performance data. (2) Proposed a mobile computing method based on director semantic annotation (DSA) as the core computing module of TSN. (3) A spatial dynamic line (SDL) model and a creative activation mechanism (CAM) based on DSA are proposed to realize fast and efficient PCC of dance with the TSN architecture. Experimental results show that the TSN architecture proposed in this article is reasonable and effective. The SDL model achieved significantly better performance with little time increase and improved the computability and aesthetics of PCC. New research ideas are proposed to solve the computational problem of PCC in complex environments.

1. Introduction

In recent years, the cultural industry has become increasingly prosperous, and people's aesthetic of performing arts has continued to increase. The ability to present a wonderful performance creative has become a key factor in gaining audience recognition according to Lee [1]. Due to the limitation of time and space, the traditional creative process of performance has systemic problems such as low creative efficiency and unsatisfactory creative effect. The specific ones can be summarized as the following three points: First of all, in the traditional performance process, the performance data generated at each stage from creativity to implementation cannot be effectively implemented and fed back. It is mainly reflected in the inability of effective training and implementation of the creative data of the creators in the early stage and the sensory data of actors and audiences without effective feedback channels, and it is even difficult to attract the attention and reference of the creators. Secondly, due to the limitation of time and space, it is difficult to achieve a complete and effective implementation of the multielement performance choreography, such as stage design, actor training, and stage scheduling. It is mainly reflected in the difficulty of performing stage training for actors at the performance site. The implementation of stage design and performance creativity on site is difficult to achieve complete reproduction in the alternate training venue, which limits the effective implementation of performance creativity in the space-time dimension. Finally, there is no quick and effective method to evaluate the effect of performance creativity, resulting in a decrease in the director's ability to recreative performance, mainly reflected in the lack of objective and high-quality evaluation data to evaluate and describe performance creativity, fuzzy performance evaluation standards, diversified evaluation data, and low evaluation efficiency. Directors lack accurate feedback mechanisms and evaluation features, and it is difficult to organize effective recreation. From this point of view, the key reasons for restricting the performance creative choreography (PCC) are the lack of effective decision-making closed loops and the lack of data feedback capabilities at different stages of the performance.

In order to solve the above problems, this paper starts from the basic principles of the world that constitute the physical domain, energy domain, and information domain, using computer technology to analysis and processing of the information domain to feed back and evaluate the energy domain and physical domain. Based on this concept, this paper treats PCC as a complex system and transforms the director experience of creative performance into computable complex system problems. In order to solve complex system problems, Darema [2] proposed a dynamic data-driven application system (DDDAS), which uses dynamic feedback and control between modelling simulation and experiment, making the simulation system execute in the process, and the data generated by the actual system can be dynamically obtained and responded. Grieves [3–5] proposed the concept of digital twin in 2003 to solve the interaction problem between real and virtual systems around the product lifecycle management (PLM), use data to connect the physical world and the virtual world, and realize multidisciplinary, multiscale, and multiprobability complex system simulation through data transfer between models. In 2011, the US Air Force Research Laboratory (AFRL) and the National Aeronautics and Space Administration (NASA) proposed to build a digital twin of the future aircraft [6]. Since then, the digital twin model system has been continuously expanded and extended. In 2014, Cerrone et al. [7] proposed the finite element model of the digital twin. Tavares et al. proposed an MVV model based on digital twins [8]. Tao et al. [9] extended the three-dimensional model of the digital twin and proposed a five-dimensional model of the digital twin, that is, physical entities, virtual entities, services, twin data, and the connection between various components, and proposed a digital twin system standard. It can be seen that the digital twin technology has a great advantage in solving the information domain problem of the physical world and the virtual world.

The physical and energy domain are also the key factors in solving complex system problems. In recent years, the Internet of Things (IoT) technology has been applied to many areas of our lives [10, 11], radio frequency identification (RFID) and sensor networks have emerged as the times require, and the new social system of the Internet of Everything is changing the human attitude and traditional cognition of society. With the support of 5G communication technology, the emergence of new computing methods such as edge computing [12] and fog computing [13] has greatly improved the interaction between IoT and smart objects, and a large number of objects have emerged, networking technical specifications and new semantic mobile computing modules [14, 15]. The complex IoT network that integrates large-scale smart sensors and the ubiquitous computing platform has become a powerful guarantee for semantic mobile computing [16, 17]. The rapid development of these emerging technologies provides new forms and possibilities for the data description and definition of the physical and energy domain of complex systems. In the traditional performance field, the data description and feedback mechanism between performance elements have become a core factor restricting the PCC. How to define and describe the complex system of PCC is the key to solving the problem.

In summary, this paper regards sensor networks, semantic mobile computing, and digital twins as key technologies and research objects in the physical domain, energy domain, and information domain in the complex system of PCC. The performance data is used as the information description of creative choreography, the sensor network is introduced into the information interaction framework of the digital twin, and the "twin sensor network" (TSN) is established as the performance data acquisition and calculation node.

The main contributions of this study are summarized as follows:

(i) A twin sensor network (TSN) architecture based on digital twin information interaction is proposed, which defines the acquisition method, classification (creative data, rehearsal data, and live data), and spatiotemporal features of performance data and describes the feedback mechanism and symbiosis between performance data in the complex environment

(ii) A mobile computing method based on director semantic annotation (DSA) is proposed, which establishes the mapping relationship between director experience and performance data for the first time and reduces the difference of performance data feature distribution under the conditions of experience constraints

(iii) A spatial dynamic line (SDL) model based on DSA is proposed for dance creative choreography, and a creative activation mechanism (CAM) is established to achieve fast and efficient performance with the TSN architecture

This paper is organized as follows: Section 2 reviews the related works. Section 3 details the methods proposed in our research. Section 4 presents the experiment results. Section 5 summarizes and looks forward to the future work.

2. Related Works

In this chapter, we briefly summarize the recent research work on sensor networks and digital twin technology and propose the research motivation and ideas for constructing TSN.

2.1. Affective Computing Based on Sensor Network. With the rapid development of smart mobile devices, the use of sensors has become widespread. At present, the application of sensors is not only sensing, but accurate and fast data calculation and research, making full use of the advantages of lightweight and mobile computing of sensor nodes to provide users with accurate and effective intervention measures. For example, mobile devices such as smart phones, in addition to the conventional physical positioning based on GPS, also integrate a large number of built-in multimodal sensors. These sensors can quickly perceive changes in the human body state and play a positive role in human health and emotion prediction [18–20]. Sleep quality detection based on time characteristics has been used in the medical field to assist in the treatment of diseases [21, 22]. Obtaining the physiological characteristics of the human epidermis to determine vital signs and abnormal state monitoring has gradually become a hot spot for physiology and psychology experts [20, 23]. The noninvasive EEG signal analysis technology played a decision-making role in grasping emotional changes and emotional cognition and provided a variety of new possibilities in judging the human body's stress response after stimulation and psychological adjustment strategies [24, 25]. Wang et al. [24] used GSR signals to simultaneously monitor the emotional state of 15 subjects in live performances. The research conducted a cluster analysis of all the audiences through the obtained GSR values and found that the data of 10 subjects were closely related. Martella et al. [25] analysed the audience's feedback in live performances, used a three-axis accelerometer to calculate the acceleration of the subject's body movements, and integrated complex emotional experiences such as "Enjoyment" or "Immersion" for quantification. By calculating the dynamic changes of acceleration, the accuracy of the study on whether the audience is in an "enjoying state" has reached nearly 90%.

Loprinzi et al. [26] proposed a cognitive emotional model to assess physical activity based on experience and to evaluate the exercise habit and intensity of adults. The emotional changes can be seen after the acute exercise, and it is related on the exercise intensity and exercise cycle of the volunteers. At the same time, personal health will also have an impact on emotional changes, which shows that this measurement method has inevitable flaws in its universality. A method of using emotional calculation to evaluate football players was proposed by Liu et al. [27], which combines the text information of the postmatch report and emotional calculation to measure the performance quality of the players. The authors established a player performance evaluation model based on LSTM; however, this method still has some problems to be solved. For example, it is difficult to achieve accurate statistics and quantification of specific behaviours in the game, which has a greater impact on the collection and evaluation of key information. Pinto et al. [28] processed electrocardiogram, electromyography, and dermal electrical activity to find a physiological model of emotion. Using samples of 55 healthy subjects, Pinto et al. used single-peak and multipeak methods to analyse which signals or combinations of signals can better describe emotional responses. Zhang [29] proposed a multimodal emotion recognition method using deep autoencoders for facial expressions and EEG interactions. The decision tree is used as the target feature selection method. Then, based on the facial expression features recognized by the sparse representation, the solution vector coefficients are analysed to determine the facial expression category of the test sample. After that, the bimodal depth autoencoder was used to fuse EEG signals and facial expression signals.

Affective computing based on sensor networks has made great progress in audience emotion detection, athletes' physiological state feedback, and auxiliary medical care. It can be seen from this that with the support of the IoT technology, the application of sensor networks has opened up a new approach for the traditional information industry and established an analysis method and quantitative model based on emotion and cognition in physical information monitoring and feature acquisition. In the traditional performance process, creative information has not yet received effective recognition and feedback.

2.2. Digital Twin Modelling. Digital twin technology is more and more widely used in system engineering. Since 2002, it has been transformed from a concept to a system engineering model, and the status and operating data of the system are continuously updated and maintained throughout the life cycle [30]. With the continuous development of 5G technology, it has promoted the further innovation of smart cities including the digital twin technology of IoT, and digital infrastructure has become the basis for the transformation of traditional industries [31]. People began to create a mirrored world, which can copy and manipulate physical objects (material domains) and control the real world through the resulting data changes [32]. Create digital twins with existing software and operating systems and establish new ideas for simulation and solving complex system problems [33]. Ding et al. [34] proposed a digital twin-based cyber-physical production system (DT-CPPS) and discussed the operating mechanism of supporting mechanisms and real-time data-driven control methods, including status data perception, intelligent interaction, and autonomous decision-making. Wang et al. [35] further analysed the monitoring, management, and durability of the human-machine collaboration system and proposed a human-computer collaboration modelling method based on digital twins to provide a comprehensive perception of products and technologies. This method has greatly inspired the traditional performance field, and it has proposed new forms and focus on performance data acquisition and feature fusion.

Autiosalo et al. [36] introduced a common method to analyse and construct digital twins in various applications. We have identified the common characteristics of digital twins from earlier documents and proposed an analysis method based on these characteristics to compare digital twin examples. This method is used to verify the presence of features and can be further enhanced. Jones et al. [37] provided the characteristics of digital twin, recognition gap knowledge, and necessary areas for future research. When characterizing digital twins, concepts, key terms, and the state of related processes are identified, discussed, and merged to produce 13 features (physical entity/twin, virtual entity/twin, physical environment, virtual environment, state, realization, metrology, twin, twin rate, physical to virtual connection/twin, virtual to physical connection/twin, physical process, and virtual process) and a complete framework of digital twin and its operating process. A quantitative model of sustainable design was established by He et al. [38]. Used the entropy method to determine the weight of the subindices, established the decision matrix of the indicators to be evaluated, reflected the obtained quantitative indicators on the digital twin data flow system, and improved the comprehensive performance of the product in sustainable design through data fusion, and proved the design and the feasibility of the use process.

A large amount of performance data is generated at different stages of the performance, and these data can only be used as accessories for different stages at present. The PCC cannot be realized without the formation of effective data features and data-driven effective feedback. The results of on-site training cannot be clearly fed back, and there is an information barrier between the director and the actors. The emergence of digital twin modelling technology provides technical support for the loop and feedback of performance data. Performance data acquisition, feature extraction, feature fusion, and data-driven modelling methods will form new and reliable feedback values between the physical world and the virtual world.

2.3. Space Trajectory in Performance Choreography. In recent years, more and more drone performances have become the focus of people's attention. Path planning is the primary issue of UAV collaborative control. Due to the complexity and diversity of UAV cluster path planning, a lot of research has focused on UAV cluster path planning models. In addition to the commonly used planning space representation, there are also methods such as target planning and conditional constraints. In addition to successfully avoiding collisions, the formation of drones must also ensure the smoothness and smoothness of the flight path according to Xu et al. [39], Dong et al. [40], and Ren et al. [41]. Xu et al. [42] and Gu and Deng [43] tried to transform the formation of the crowd into key frame matching and path planning between people. However, in stage performances, this key frame matching and movement method still lacks a certain degree of integrity and aesthetics for expressing artistic effects.

In the process of creative choreography of dance, the most important thing is to enhance the effect of choreography through its own spatial movement and the beauty of the movement trajectory to realize the choreography creativity. The dance choreography mentioned in this article mainly refers to the stage space scheduling choreography of single dance, double dance, and group dance. The planning of stage plays and musicals needs to consider the development of the story and the overall planning of the language interaction between the characters, which is quite different from the choreography mode of dance, so it is not the research scope of this article. In this process, you will definitely encounter various space constraints and behaviour constraints in the performance scene and draw a motion curve with artistic beauty as much as possible without trajectory conflict. Xu et al. [39] proposed a scheme that can automatically generate a visually beautiful crowd key frame motion trajectory. Although it can control a large-scale crowd from the perspective of a cluster, it has certain defects in detail optimization and aesthetic enhancement. Ren et al. [41] and Xu et al. [44] proposed many different methods to simulate the conversion of crowd formations, and Takahashi et al. [45] proposed a spectrum-based crowd movement route control method, but these methods have computational memory limitations on the identification and designation of the key frame.

Wang et al. [46] proposed a real-time obstacle avoidance path tracking algorithm, which enables the UAV to avoid large unknown static and moving obstacles in time and fly to the target after avoiding obstacles during path tracking. Wang et al. [47] proposed a path following method based on virtual force, which compensates the influence of the reference curvature for the circle and the curve of the curvature over time. The design idea of this proportional-differential controller is on the stability and convergence of the trajectory movement. It has certain practical significance and lacks subjective cognition and aesthetic laws in the planning of crowd movement on stage. In the research of crowd simulation, in addition to the study of the shape template and the shape constraint of the controller by Chang and Li [48] and Gu and Deng [49], more attention is paid to the efficiency of crowd reaching the destination according to Golas et al. [50] and Zhao et al. [51].

In the past few years, the technology of space-time mapping of people in a virtual environment has become a mainstream research method, especially in the fields of movies, games, and simulation applications. Ramirez et al. [52] proposed an optimization-based method to generate a smooth collision-free trajectory for the crowd, and the cubic spline curve method played a good role in smoothing the trajectory. Jordao et al. [53] fill people with visual characteristics in a large virtual environment, provide a solution for the artist's spatial composition design, and introduce a specific stage after each iteration to avoid using the global pathfinding process to create local cycle. Discretize the environment into regular patches and meet the overall density and traffic restrictions by updating the direction of the agent in the patch. This optimization method has a certain driving effect on artistic creation. Barnett et al. [54] use Reeb graph to represent the topology of the environment and calculate the maximum capacity of each path in the graph. Lightweight algorithms are used to perform crowd path planning, and advanced parameters such as collaboration and congestion levels can be used to control crowds, saving a lot of computing time in a comprehensive system for rapid crowd interaction control. Toll [55] uses a multilayer navigation network to construct a path planning algorithm in a complex virtual environment, which provides a new idea for large-scale dynamic crowd simulation and a crowd relationship diagram describing multilayer complex environments.

This paper believes that the core problem of PCC for dance is to calculate the trajectory of the actors in the stage space and optimize the trajectory to meet the standards of dance aesthetics. This poses a challenge to the ways and methods of PCC for dance: first, how to draw the trajectory of the actors, and secondly, how to evaluate the drawn trajectory quantitatively. The method of PCC determines whether the original creative can be realized quickly and effectively, especially the PCC for dance. It is necessary to gather high-quality experience and digital choreography to meet the needs of performance creative. Among them, the stage space scheduling of dance performances is the most important part of the choreography, but the traditional space scheduling method relies on the choreographer and actors performing repeated manual rehearsals. This process caused a lot of waste of resources and time consumption, and the final

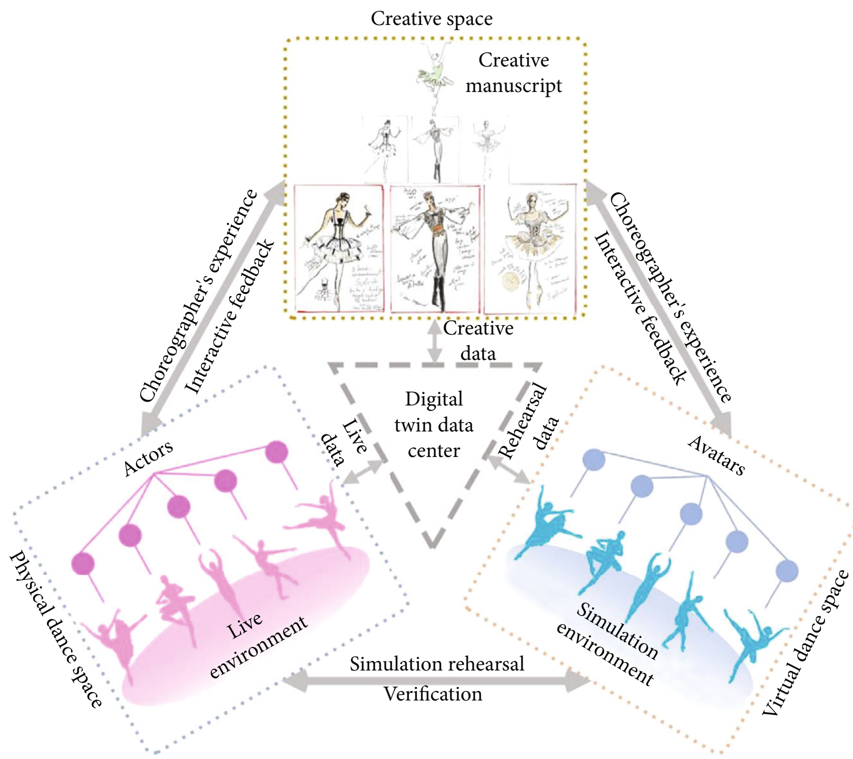

Figure 1: Dance digital twin space (DDTS).

orchestration effect cannot be determined as the optimal solution. So, the PCC for dance begins to show its research value and practical significance.

3. Materials and Methods

3.1. Dance Digital Twin Space (DDTS). This paper conducts a detailed analysis and research on the concept and development of digital twins, especially the system framework of the digital twin workshop [56]. Combining the traditional choreography process and choreographer's feedback, a digital twin space for creative choreography is proposed (see Figure 1).

As shown in Figure 1, DDTS is composed of a physical dance choreography space (PDS), a virtual choreography workshop (VDS), a choreographer creative space (CS), and a digital twin data center (DTDC).

The specific operating mechanism of the digital twin framework: Firstly, in the creative space, the choreographer can draw the manuscript based on experience and creative needs to form visual original creative data. Then, use the experience and creative data of the choreographer as the input of the virtual choreography space and perform virtual choreography of the choreographer's manuscript in the virtual environment. In this space, you can provide choreography feedback to the creative space at any time and assist the choreographer to redesign the creative plan. After that, the virtual choreography space uses the simulation rehearsal data as the input of the physical choreography space to guide the training and choreography of real dancers, and the display data of the physical choreography space verifies the feasibility of the simulation rehearsal data. Finally, the live data of the physical choreography space is fed back to the creative space and provides feedback and redesigns reference for live performance effects for choreographers.

In this closed-loop twin computing framework, three different digital spaces are gathering the generated data in the digital twin data center. In this data center, the process data and redesign data of the entire dance choreography are accumulated and integrated to choreograph. Provide strong data support and computability verification for each link. The behavioural interaction and data interaction of the entire dance digital twin space will continue to occur until the choreographer believes that the design plan has the performance conditions in terms of feasibility and aesthetic imitation, and the closed-loop iterative operation of the framework can be terminated.

3.2. Twin Sensor Network (TSN). In this paper, the sensor network is regarded as a key link in solving the complex system problem of PCC, and performance data is used as the information description of creative choreography. The sensor network is introduced into the information interaction framework of the digital twin. For the DDTS proposed above, the twin sensor network (TSN) is established as a performance data acquisition and calculation node. The design architecture of TSN is shown in Figure 2.

The core of digital twin technology is to connect data and information between the physical world and the virtual world. The TSN architecture mainly includes four modules:

(1) The sensor node, for obtaining performance data, collects the raw data of the performance, including

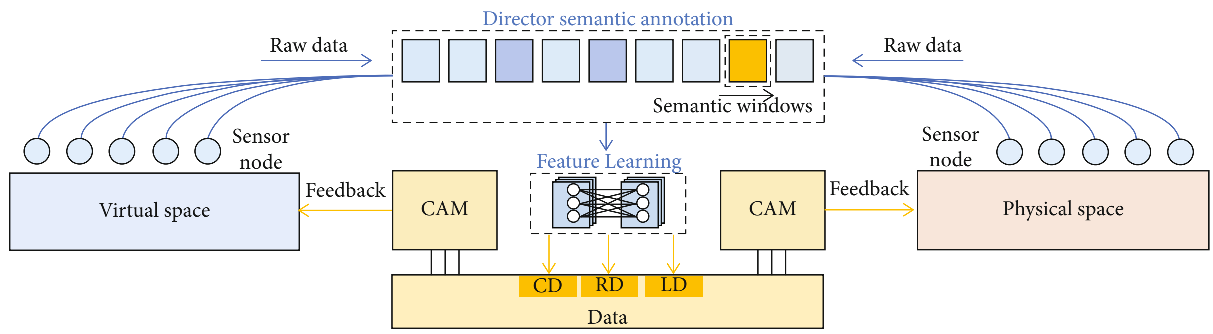

Figure 2: Twin sensor network (TSN).

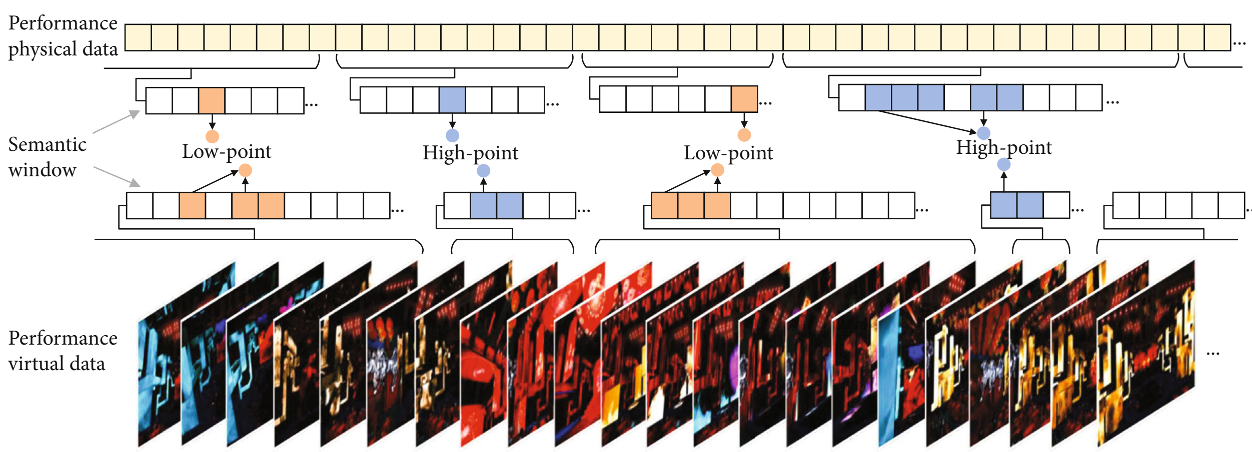

Figure 3: Director semantic annotation (DSA).

multimodal data types such as performance environment, director creativity, actor training, and audience feedback. These data describe the performance from different subjective and objective perspectives, which include the following: EEG signal acquisition uses the whole brain induction head-mounted device, which consists of 14 channel sensors and 2 bipolar reference electrodes, samples at a rate of 128 Hz. The data collection of the audience's facial expressions uses a conventional high-definition camera with an image resolution of 1920*1080, a smart bracelet to collect the audience's heart rate. The device uses a PPG heart rate sensor, a three-axis acceleration sensor, and a three-axis gyroscope

(2) Director semantic annotation (DSA) is one of the innovations proposed in this paper. Aiming at the professionalism and particularity of performance data, DSA uses a supervised model training method to label the training set and test set to achieve the most effective training results. According to the creative intention and aesthetic experience of the performance work, the director defined and marked the high point, normal point, and low point of the performance creative. Among them, high point corresponds to positive and wonderful ideas, normal point corresponds to general reasonable ideas, and low point corresponds to negative failed ideas (see Figure 3)

(3) After the DSA preprocesses the raw sensor data, the feature learning module extracts features and assigns different time tags to the corresponding data type window [16, 57] (see Figure 4).

(4) The creative activation mechanism (CAM) is explained in Section 3.3.

The digital twin technology integrates the data, models, calculation logic, simulation, and sensor feedback of the physical world and the virtual world to draw a complete twin computing system and twin life mechanism [58, 59]. We map the physical space and virtual space of creative choreography to three choreography stages: creative stage, rehearsal stage, and live stage, and propose a computable framework for PCC based on digital twins (see Figure 5).

Among them, the virtual space in the creative stage reflects the creative motivation and experience of the choreographer, including creative motivation, aesthetic experience, theme selection, and creation rules. The creative data feedback from the virtual space includes manuscript data, emotion data, and copyright data. These data are mainly the concrete definition of the choreograph through the creative manuscripts and literary descriptions of the

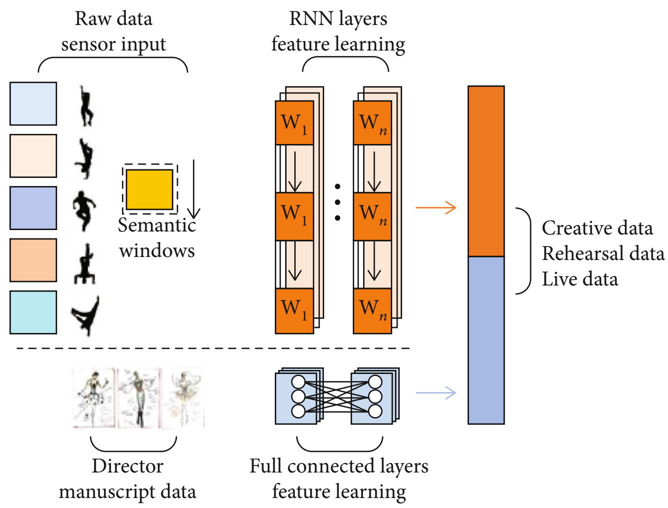

Figure 4: Feature learning.

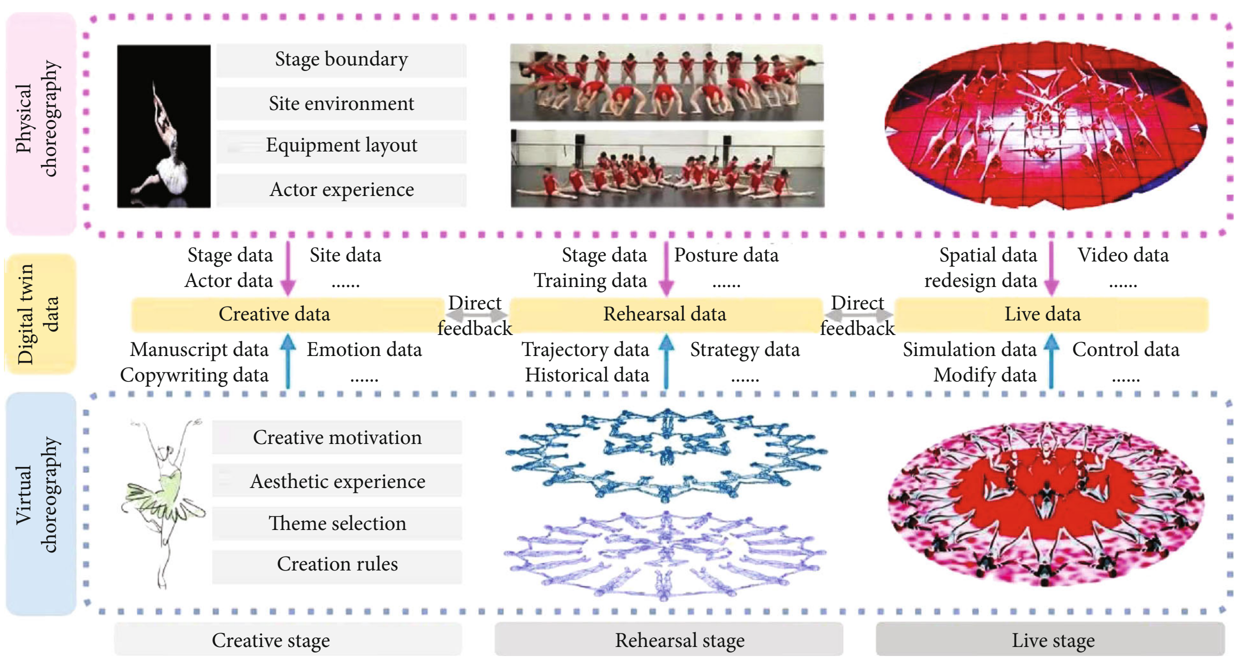

Figure 5: Computable framework for PCC based on digital twins.

choreographer. The relevant design elements of the physical space in the creative stage include stage boundary, site environment, equipment layout, and actor experience. The creative data feedback from the physical space includes stage data, site data, and actor data. These data are the description of the objective characteristics of the physical space. It reflects the objective attributes of the physical choreography space. These characteristics and attributes provide a perceptual experience for the creative ideas of the choreographer. But at the same time, there are corresponding boundary restrictions and constraints on the creative choreography process.

In the rehearsal stage, the virtual space normalizes and standardizes the creative manuscript data of the editor and choreographer to form rehearsal data suitable for training, including trajectory data, strategy data, and historical data. The physical space mainly provides a suitable environment for the training of actors. During the training process of the physical space, the corresponding rehearsal data is fed back, including stage data, posture data, and training data. These data have extremely high feedback value and redesign basis for the rehearsal process.

In the live stage, the virtual space performs full-element simulation of the complete dance performance, including stage sound, light, electricity, and other dance environment data, actor's body movement data, and space scheduling data. Provide simulation data, control data, and modify data for live data. The physical space provides a real-stage environment for dance performances and real spatial data, video data, and redesign data for live data. These data provide a good redesign standard and basis for the rehearsal process

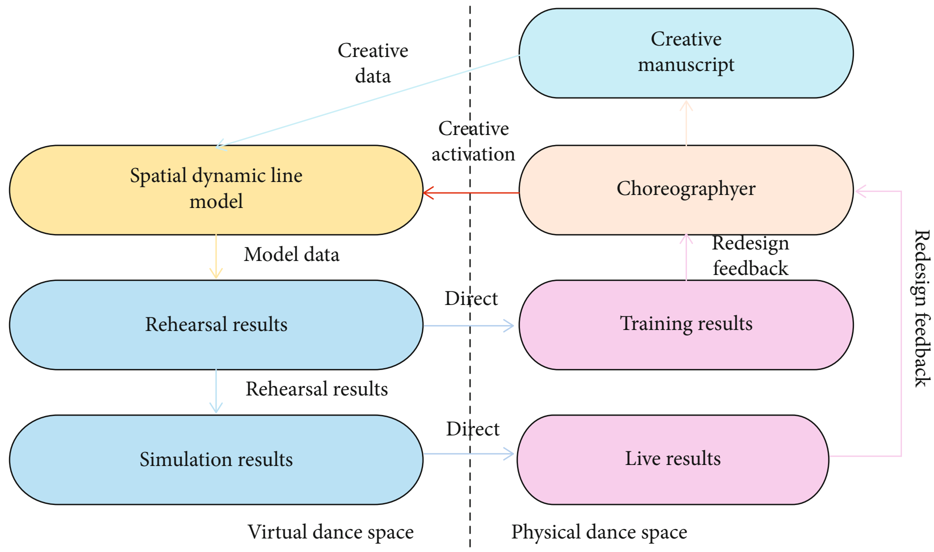

FIGURE 6: Spatial dynamic line (SDL) model.

and provide real environmental constraints and performance status feedback to the creative realization of the choreographer. In digital twin data, creative data, rehearsal data, and live data are standardized corresponding to three different stages. Creative data provides creative concepts for rehearsal data, and rehearsal data provides training standards for live data. On the contrary, live data puts forward the basis of redesign for rehearsal data, and rehearsal data puts forward the constraint conditions for optimizing creativity for creative data. The computable framework for PCC proposed in this paper double-maps the physical and virtual spaces of the different stages of dance choreography and connects and integrates the performance characteristics of each stage through the iterative symbiosis relationship of twin data. This is the first time in the field of artistic creation that creative choreography has been transformed into a computable digital twin framework.

3.3. Spatial Dynamic Line (SDL) Model. In this work, we dynamically incorporate feedback based on mutual information into SFM. We briefly described the concept of mutual information and how it can be applied to measure the trajectory of actors [39]. Mutual information (MI) is a well-known concept in the field of information theory. It is designed to quantify the interdependence between two random variables as the Equation (1).

$$I(G, H) = \sum_{i,j} p(g_i, h_j) \log_n \frac{p(g_i, h_j)}{p(g_i)p(h_j)}. \quad (1)$$

Among them, $p(g_i)$, $p(h_j)$, and $p(g_i, h_j)$ are the individual probability distribution and joint probability distribution of g and h, respectively. It is important to insert more than two key frame structures. In the current framework, users are allowed to insert new intermediate key frame structures. We use the method of [45] to allow the director to generate new key frame data to activate and interfere with the existing motion trajectory as the Equation (2).

$$p(t) = c_{-1}p_{n-1} + c_0 p_n + c_1 p_{n+1} + c_2 p_{n+2}. \quad (2)$$

The spatial dynamic line (SDL) model proposed in this article is shown in Figure 6.

In our proposed model structure, the choreographer can obtain feedback on the choreography effect through training results and live results. The core idea of the SDL model is to accept the creative activation of the choreographer at any time, fine-tune the spatial dynamic line calculated by the model, and redesign the average curvature, composition, and performance in the spatial.

This article proposes that the advantage of CAM compared to [53–55] is that the performance data is formed into a partial loop during the rehearsal stage, and the director's intention is transformed into recreation in the multiple rounds of rehearsal data loops. To meet the needs of the overall creative effect, the optimization and realization of the overall plan can be achieved by changing the limitations and computing power of the local specific stages.

4. Results and Discussion

4.1. Experimental Design. This article selects the traditional folk dance work "Cutting Flowers" to verify the spatial movement model and the digital twin dance creative choreography simulation framework. The core idea of the experiment is to use the actors' initial and target positions drawn by the choreographer, calculate the spatial trajectory from the initial point to the target point by the SDL, and generate the rehearsal effect through the digital twin choreography framework until the space the trajectory of the spatial dynamic line reaches the artistic effect expected by the choreographer. In this iterative creative process, when the choreographer thinks it is necessary to redesign the rehearsal effect, the creative

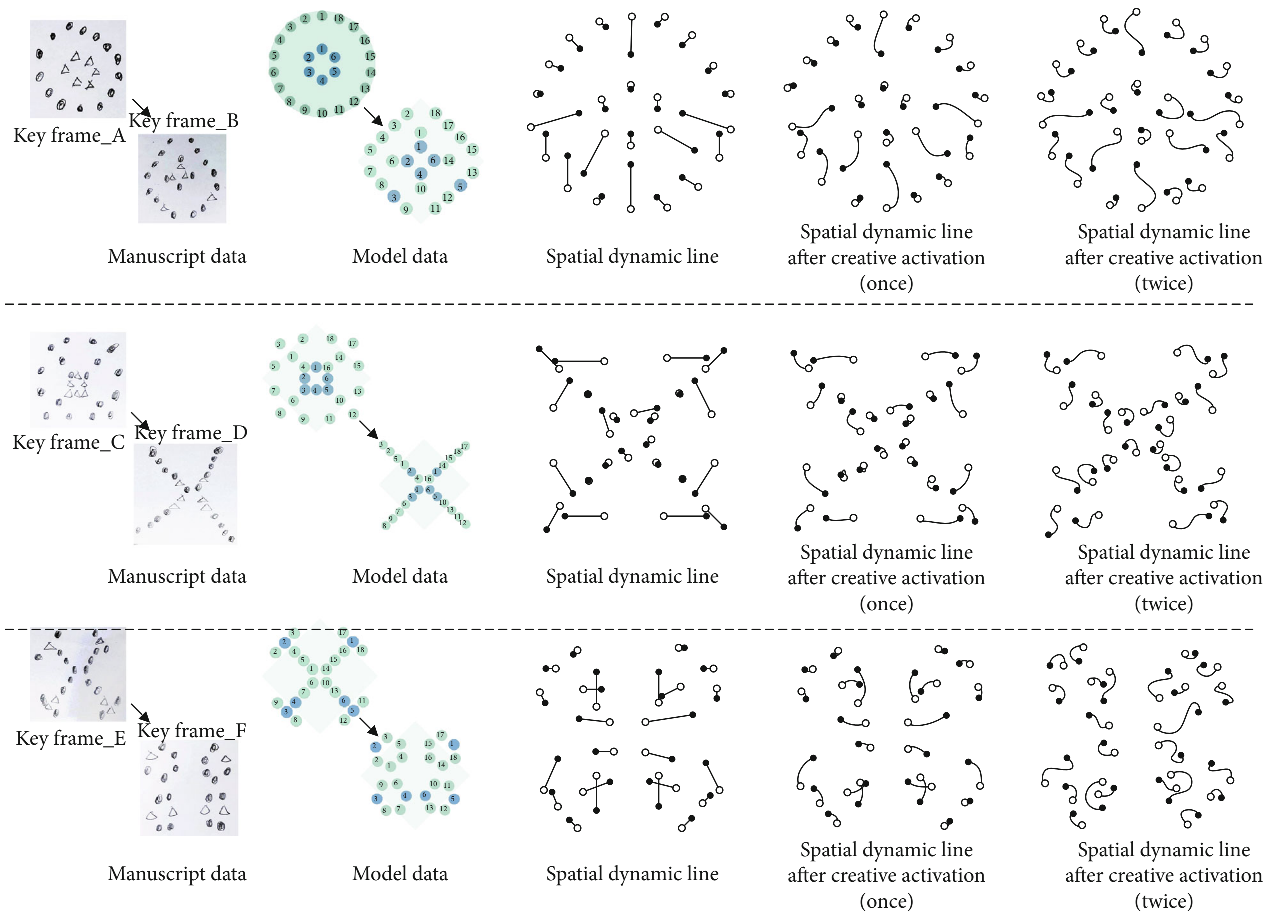

Figure 7: Spatial dynamic line effect by SDL in the dance work "Cutting Flowers."

Table 1: The performance of the SDL with no creative activation, once, and twice in the trajectory experiment from key frame A to key frame B.

Creative activation	Time (s)	Average curvature	Composition	Dance performance
None	1.37	0	1	2
Once	1.51	15.4	2	3
Twice	1.83	37.9	4	5

manuscript can be fine-tuned and used as the creative activation of the SDL to generate a spatial dynamic line that is more with creative and aesthetic needs.

The manuscript data used in the experiment was hand-drawn by the choreographer who decomposed the key frame and used two different graphic shapes to represent the group of actors in the group dance. We use time and average curvature between two points as objective evaluation indicator, composition, and dance performance (range from zero to five) as subjective evaluation indicator which scored by choreographer.

4.2. Results Analysis. This paper conducts experimental verification on dance "Cutting Flowers." Firstly, three sets of key frame transformations are decomposed from the

Table 2: The performance of the SDL with no creative activation, once, and twice in the trajectory experiment from key frame C to key frame D.

Creative activation	Time (s)	Average curvature	Composition	Dance performance
None	1.19	0	1	2
Once	1.35	10.9	3	3
Twice	1.58	27.8	4	5

Table 3: The performance of the SDL with no creative activation, once, and twice in the trajectory experiment from key frame E to key frame F.

Creative activation	Time (s)	Average curvature	Composition	Dance performance
None	1.21	0	0	2
Once	1.47	9.4	2	3
Twice	1.69	34.1	4	5

dance structure. Starting from the manuscript of the choreographer, through the model's autonomous calculation, the choreographer's first activation and the choreographer's second activation generated a spatial dynamic line effect

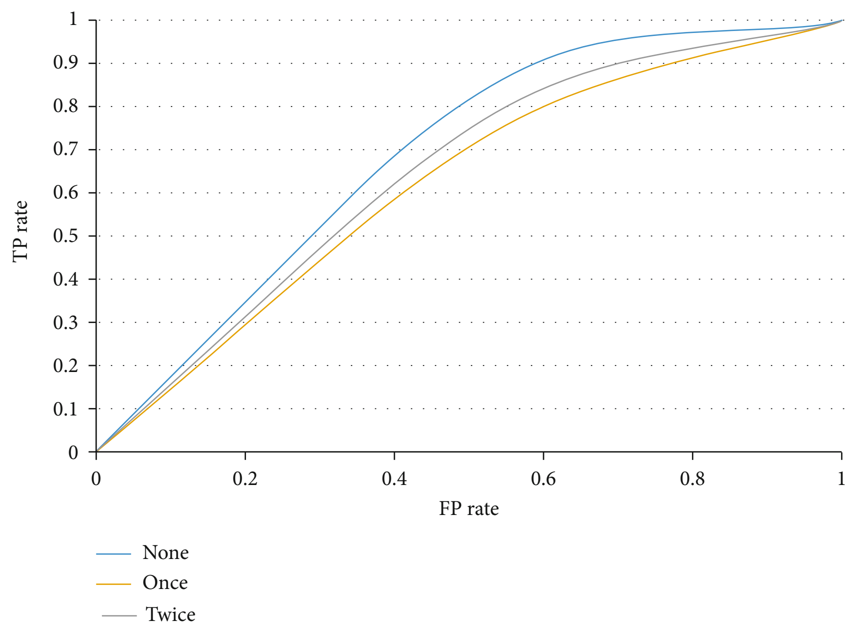

Figure 8: ROC curve of model.

(see Figure 7). Each line represents the performance of spatial dynamic line with no creative activation, one creative activation, and two creative activations. From Tables 1–3, we can see that our model obtains a significantly better performance with very few time increase than the method without creative activation.

The ROC curve of model is shown in Figure 8 during different circumstances (no creative activation, one creative activation, and two creative activation).

From the experimental results, the TSN, SDL, and CAM proposed in this paper are effective and have reached the research expectations of this paper. From Tables 1–3, we can further conclude that with the increase in the number of creative activations, the calculation time has increased slightly, but the average curvature of the spatial trajectory of dance scheduling has been greatly improved, and the dance structure has been powerful which performed. Secondly, from the performance of the SDL model, when the key frame change area is not obvious (key frames E to F), the average curvature increase rate is 2.034% higher than when the key frame change area is more obvious (key frames A and B). This shows that the SDL and CAM proposed in this article have great assistance and driving force for the creative promotion of dance choreographers and the efficiency of on-site scheduling.

At present, the experimental environment and manuscript data of this article still have limitations to a certain extent. For example, the manuscript data used in this article does not have a certain stage boundary in the screen, and it is a single-tone hand-drawn sample. These factors will be improved in the next experiment, adding clear stage boundaries and conditional constraints boundaries and discussing the influence of the multicolor hand-painted background on the SDL model and the improvement of the director's creative emotions.

5. Conclusions

The purpose of this article is to use the digital twin framework to perform creative choreography. To achieve this goal, we first build a dance digital twin space (DDTS) for creative choreography of dance performances. Mapped the choreography in physical and virtual spaces; after that, we proposed the twin sensor network (TSN) as a performance data acquisition and calculation node. Through the symbiosis relationship of performance data (creative data, rehearsal data, and live data), the whole process of PCC is described, which solves the waste of resources caused by traditional nondigital choreography. Finally, we proposed a spatial dynamic line (SDL) model and creative activation mechanism (CAM), allowing the choreographer to achieve creative activation and redesign of dance choreography through a TSN architecture.

Experimental results show that the TSN architecture proposed in this article is reasonable and effective. The SDL model achieved significantly better performance with little time increase and improved the computability and aesthetics of PCC. New research ideas are proposed to solve the computational problem of PCC in complex environments.

Data Availability

The data used to support the findings of this study have not been made available because commercial reasons.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] I.-S. Lee, "Performing arts in the age of transmedia," *Journal of Acting Studies*, vol. 17, no. 2, pp. 17–32, 2020.

[2] F. Darema, "Dynamic data driven applications systems: a new paradigm for application simulations and measurements," in *International Conference on Computational Science*, pp. 662–669, Berlin, Heidelberg, 2004.

[3] M. W. Grieves, "Product lifecycle management: the new paradigm for enterprises," *International Journal of Product Development*, vol. 2, no. 1/2, pp. 71–84, 2005.

[4] M. W. Grieves and M. Tanniru, "PLM, process, practice and provenance: knowledge provenance in support of business practices in product lifecycle management," *International Journal of Product Lifecycle Management*, vol. 3, no. 1, pp. 37–53, 2008.

[5] M. Grieves, "Digital twin: manufacturing excellence through virtual factory replication," *White paper*, vol. 1, pp. 1–7, 2014.

[6] E. Glaessgen and D. Stargel, "The digital twin paradigm for future NASA and U.S. Air Force vehicles," in *53rd AIAA/ASME/ASCE/AHS/ASC structures, structural dynamics and materials conference 20th AIAA/ASME/AHS adaptive structures conference 14th AIAA*, Honolulu, Hawaii, 2012.

[7] A. Cerrone, J. Hochhalter, G. Heber, and A. Ingraffea, "On the effects of modeling as-manufactured geometry: toward digital twin," *International Journal of Aerospace Engineering*, vol. 2014, 10 pages, 2014.

[8] P. Tavares, J. A. Silva, P. Costa, G. Veiga, and A. P. Moreira, "Flexible work cell simulator using digital twin methodology for highly complex systems in industry 4.0," in *Iberian Robotics conference*, pp. 541–552, Cham, 2017.

[9] F. Tao, X. Ma, T. Hu, Z. Huang, J. Cheng, and Q. Qi, "Research on digital twin standard system," *Computer Integrated Manufacturing Systems*, vol. 25, no. 10, pp. 2405–2418, 2019.

[10] T. Su, S. Shao, S. Guo, and M. Lei, "Blockchain-based internet of vehicles privacy protection system," *Wireless Communications and Mobile Computing*, vol. 2020, no. 5, pp. 1–10, 2020.

[11] M. S. Mahmoud and A. A. Mohamad, "A study of efficient power consumption wireless communication techniques/modules for internet of things (IoT) applications," *Advances in Internet of Things*, vol. 6, no. 2, pp. 19–29, 2016.

[12] Z. Li, R. Xie, and L. Sun, "A survey of mobile edge computing," *Telecommunications Science*, vol. 34, no. 1, pp. 87–101, 2018.

[13] A. Arif and A. Ejaz, "A survey on mobile edge computing," in *10th IEEE international conference on intelligent systems and Control*, Coimbatore, India, 2016.

[14] F. Li, D. Wang, Y. Wang et al., "Wireless communications and mobile computing blockchain-based trust management in distributed internet of things," *Wireless Communications and Mobile Computing*, vol. 2020, no. 5, pp. 1–12, 2020.

[15] M. A. Imran, A. Zoha, L. Zhang, and Q. H. Abbasi, "Grand challenges in IoT and sensor networks," *Frontiers in Communications and Networks*, vol. 1, 2020.

[16] I. Perez-Pozuelo, D. Spathis, E. A. Clifton, and C. Mascolo, "Wearables, Smartphones, and Artificial Intelligence for Digital Phenotyping and Health," *Digital Health*, pp. 33–54, 2021.

[17] Z. Tian, D. Liu, W. Chen, W. Wang, S. Pan, and N. Guo, "Analysis and optimization of asymmetric wireless power transfer in concrete," *Wireless Communications and Mobile Computing*, vol. 2020, 12 pages, 2020.

[18] R. Wang, M. S. Aung, S. Abdullah et al., "Crosscheck: toward passive sensing and detection of mental health changes in people with schizophrenia," in *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, pp. 886–897, Heidelberg Germany, 2016.

[19] X. Zhang, W. Li, X. Chen, and S. Lu, "Moodexplorer: towards compound emotion detection via smartphone sensing," *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, vol. 1, p. 176, 2018.

[20] N. Jaques, S. Taylor, A. Sano, and R. Picard, "Multimodal autoencoder: a deep learning approach to filling in missing sensor data and enabling better mood prediction," in *International Conference on Affective Computing and Intelligent Interaction (ACII)*, San Antonio, Texas, 2017.

[21] S. Servia-Rodríguez, K. K. Rachuri, C. Mascolo, P. J. Rentfrow, N. Lathia, and G. M. Sandstrom, "Mobile sensing at the service of mental well-being: a large-scale longitudinal study," in *Proceedings of the 26th International Conference on World Wide Web, International World Wide Web Conferences Steering Committee*, pp. 103–112, Perth Australia, 2017.

[22] Y. Suhara, Y. Xu, and A. Pentland, "Deepmood: forecasting depressed moodbased on self-reported histories via recurrent neural networks," in *Proceedings of the 26th International Conference on World Wide Web, International World Wide Web Conferences Steering Committee*, pp. 715–724, Perth Australia, 2017.

[23] N. Jaques, O. O. Rudovic, S. Taylor, A. Sano, and R. Picard, "Predicting tomorrow's mood, health, and stress level using personalized multitask learning and domain adaptation," in *Proceedings of IJCAI 2017 Work-shop on Artificial Intelligence in Affective Computing, volume 66 of Proceedings of Machine Learning Research*, pp. 17–33, Melbourne, Australia, 2017.

[24] C. Wang, E. N. Geelhoed, P. P. Stenton, and P. Cesar, "Sensing a live audience," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 1909–1912, Toronto, Canada, 2014.

[25] C. Martella, E. Gedik, L. Cabrera-Quiros, G. Englebienne, and H. Hung, "How was it? Exploiting smartphone sensing to measure implicit audience responses to live performances," in *Proceedings of the 23rd ACM International Conference on Multimedia*, pp. 201–210, Brisbane Australia, 2015.

[26] P. D. Loprinzi, S. Pazirei, G. Robinson, B. Dickerson, M. Edwards, and R. E. Rhodes, "Evaluation of a cognitive affective model of physical activity behavior," *Health Promotion Perspectives*, vol. 10, no. 1, pp. 88–93, 2020.

[27] W. Liu, X. Xie, S. Ma, and Y. Wang, "An improved evaluation method for soccer player performance using affective computing," in *2020 3rd International Conference on Artificial Intelligence and Big Data (ICAIBD)*, Chengdu, China, 2020.

[28] G. Pinto, J. M. Carvalho, F. Barros, S. C. Soares, A. J. Pinho, and S. Brás, "Multimodal emotion evaluation: a physiological model for cost-effective emotion classification," *Sensors*, vol. 20, no. 12, p. 3510, 2020.

[29] H. Zhang, "Expression-EEG based collaborative multimodal emotion recognition using deep autoencoder," *IEEE Access*, vol. 8, pp. 164130–164143, 2020.

[30] A. Madni, C. Madni, and S. Lucero, “Leveraging digital twin technology in model-based systems engineering,” *Systems*, vol. 7, no. 1, 2019.

[31] Z. Allam and D. S. Jones, “Future (post-COVID) digital, smart and sustainable cities in the wake of 6G: Digital twins, immersive realities and new urban economies - ScienceDirect,” *Land Use Policy*, vol. 101, 2021.

[32] S. Yrjölä, *Connecting You with Your Digital Twin: 6G will Bridge the Physical with the Virtual*, 2020.

[33] M. H. Alsharif, A. H. Kelechi, M. A. Albreem, S. A. Chaudhry, M. S. Zia, and S. Kim, “Sixth generation (6G) wireless networks: vision, research activities, challenges and potential solutions,” *Symmetry*, vol. 12, no. 4, p. 676, 2020.

[34] K. Ding, F. T. Chan, X. Zhang, G. Zhou, and F. Zhang, “Defining a digital twin-based cyber-physical production system for autonomous manufacturing in smart shop floors,” *International Journal of Production Research*, vol. 57, pp. 6315–6334, 2019.

[35] T. Wang, J. Li, Z. Kong, X. Liu, H. Snoussi, and H. Lv, “Digital twin improved via visual question answering for vision-language interactive mode in human–machine collaboration,” *Journal of Manufacturing Systems*, vol. 58, no. 4, p. 24, 2020.

[36] J. Autiosalo, J. Vepsalainen, R. Viitala, and K. Tammi, “A feature-based framework for structuring industrial digital twins,” *IEEE Access*, vol. 8, pp. 1193–1208, 2020.

[37] D. Jones, C. Snider, A. Nassehi, J. Yon, and B. Hicks, “Characterising the digital twin: a systematic literature review,” *CIRP Journal of Manufacturing Science and Technology*, vol. 29, pp. 36–52, 2020.

[38] B. He, X. Cao, and Y. Hua, “Data fusion-based sustainable digital twin system of intelligent detection robotics,” *Journal of Cleaner Production*, vol. 280, p. 124181, 2021.

[39] M. Xu, Y. Wu, Y. Ye, I. Farkas, H. Jiang, and Z. Deng, “Collective crowd formation transform with mutual information-based runtime feedback,” *Computer Graphics Forum: Journal of the European Association for Computer Graphics*, vol. 34, no. 1, pp. 60–73, 2015.

[40] X. Dong, B. Yu, Z. Shi, and Y. Zhong, “Time-varying formation control for unmanned aerial vehicles: theories and applications,” *IEEE Transactionson Control Systems Technology*, vol. 23, no. 1, pp. 340–348, 2015.

[41] J. Ren, X. Jin, and Z. Deng, “Crowd Formation Generation and Control,” in *Handbook of Human Motion*, Springer, 2017.

[42] M. Xu, Y. Wu, and Y. Ye, “A smooth and efficient crowd transformation,” in *Proceedings of the 20th ACM international conference on Multimedia*, pp. 1189–1192, Nara Japan, 2012.

[43] Q. Gu and Z. Deng, “Formation sketching: an approach to stylize groups in crowd simulation,” in *Proceedings of the Graphics Interface 2011Conference*, pp. 1–8, Canada, 2011.

[44] M. Xu, H. Jiang, X. Jin, and Z. Deng, “Crowd simulation and its applications: recent advances,” *Journal of Computer Science and Technology*, vol. 29, no. 5, pp. 799–811, 2014.

[45] S. Takahashi, K. Yoshida, T. S. Kwon, K. H. Lee, J. H. Lee, and S. Y. Shin, “Spectral-based group formation control,” *Computer Graphics Forum*, vol. 28, no. 2, pp. 639–648, 2010.

[46] Y. Wang, X. P. Zhu, Z. H. Zhou, and H. Zhang, “UAV path following in 3-D dynamic environment,” *Robot*, vol. 36, no. 1, pp. 83–91, 2014.

[47] X. Wang, D. Zhang, and L. Shen, “A virtual force based path following approach for unmanned aerial vehicles,” *Robot*, vol. 38, no. 3, pp. 329–336, 2016.

[48] J. Chang and T. Li, “Simulating virtual crowd with fuzzy logics and motion planning for shape template,” in *IEEE Conference on Cybernetics & IntelligentSystems*, Chengdu, China, 2008.

[49] Q. Gu and Z. Deng, “Generating freestyle group formations in agent-based crowd simulations,” *IEEE Computer Society Press*, vol. 32, no. 1, pp. 20–31, 2013.

[50] A. Golas, R. Narain, S. Curtis, and M. Lin, “Hybrid long-range collision avoidance for crowd simulation,” *IEEE Transactions on Visualization & Computer Graphics*, vol. 20, no. 7, pp. 1022–1034, 2014.

[51] M. Zhao, J. Zhong, and W. Cai, “A role-dependent data-driven approach for high density crowd behavior modeling,” in *The 2016 annual ACM Conference*, pp. 1–25, ACM Transactions on Modeling and Computer Simulation (TOMACS), 2016.

[52] J. G. Ramirez, D. Lange, P. Charalambous, C. Esteves, and J. Pettré, “Optimization-based computation of locomotion trajectories for crowd patches,” in *Proceedings of the Seventh International Conference on Motion in Games*, pp. 7–16, Playa Vista California, 2014.

[53] K. Jordao, P. Charalambous, M. Christie, J. Pettré, and M. P. Cani, “Crowd art: density and flow based crowd motion design,” in *Proceedings of the 8th ACM SIGGRAPH Conference on Motion in Games*, pp. 167–176, Paris France, 2015.

[54] A. Barnett, H. P. Shum, and T. Komura, “Coordinated crowd simulation with topological scene analysis,” *Computer Graphics Forum*, vol. 35, no. 6, pp. 120–132, 2016.

[55] W. G. Tollvan, *Navigation for Characters and Crowds in Complex Virtual Environments*, 2017.

[56] I. Errandonea, S. Beltrán, and S. Arrizabalaga, “Digital twin for maintenance: a literature review,” *Computers in Industry*, vol. 123, p. 103316, 2020.

[57] A. Bulling, U. Blanke, and B. Schiele, “A tutorial on human activity recognition using body-worn inertial sensors,” *ACM Computing Surveys*, vol. 46, no. 3, pp. 1–33, 2014.

[58] B. Moya, A. Badías, I. Alfaro, F. Chinesta, and E. Cueto, “Digital twins that learn and correct themselves,” *International Journal for Numerical Methods in Engineering*, 2020.

[59] E. Yildiz, C. Møller, and A. Bilberg, “Virtual factory: digital twin based integrated factory simulations,” *Procedia CIRP*, vol. 93, pp. 216–221, 2020.