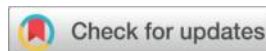




Historical Evolution, Modern Transformation and the Future of Digitalisation in Sanda: From Traditional Martial Art to Smart

Combat Sport



ZiyiJiang

Juntendo University

Dongchang Huating Community, Dongchangfu District, Liaocheng City, Shandong
Province

corresponding author: 1191399404@qq.com

1 Introduction

As a modern combat sport developed from China's traditional martial arts, Sanda has gradually transformed from practical combat techniques to regulated competitive events since the 20th century, driven by the national sports system and military-police training systems. It has become one of the fully-contact combat sports officially recognized by the International Wushu Federation, holding a significant position in domestic and international fighting competitions. The global sports field is undergoing a new wave of transformation characterized by digitalization and intelligence. Electronic protective gear and sensor-based scoring systems have been widely adopted in sports like Taekwondo to enhance the objectivity and transparency of scoring. Inertial sensors, wearable devices, and motion capture technology are increasingly becoming essential tools for evaluating striking power, technical efficiency, and training load in combat sports. Virtual reality and mixed reality platforms are also being used to simulate real combat scenarios, improving athletes' reaction capabilities and decision-making levels. Against this macro backdrop, how to build a "smart competition" development path with Chinese martial arts characteristics while respecting the traditional combat culture of Sanda and drawing on these mainstream digital solutions has become an urgent contemporary challenge.

Compared to sports like Taekwondo and boxing that have widely adopted electronic scoring systems and smart protective gear, Sanda still faces significant shortcomings in technical methods and data foundations. Most Sanda competitions currently rely heavily on referees' visual judgments and experience-based decisions. In scenarios involving multiple targets, high-intensity confrontations, and complex multi-dimensional techniques, factors like obstructions, limited viewing angles, and rapid movement complexity make it difficult to ensure complete objectivity and consistency. Systematic research on AI applications in sports reveals that while AI shows remarkable potential in posture recognition and action classification, challenges remain in handling high-speed movements, intense confrontations, frequent obstructions, and complex combinations of actions, particularly regarding recognition accuracy and real-time performance. Although studies on Sanda combat techniques have begun exploring multi-source sensor data (e.g., joint trajectories and limb angles) to build posture recognition frameworks, most efforts remain at the laboratory or small-sample validation stage, creating a noticeable gap between theoretical research and real-world competitive environments. Existing literature also highlights the lack of unified standards and best practices in sensor deployment, sampling frequency selection, and data processing workflows for combat sports. This results in limited comparability across studies and hinders the large-scale adoption and promotion of these technologies in Sanda.

In practical applications, digital innovations for Sanda and related martial arts have emerged sporadically. For instance, researchers have developed an auxiliary teaching system that integrates machine vision and human motion recognition, using motion completion assessment and real-time feedback to enhance instructional efficiency. Meanwhile, studies are exploring the creation of AI-powered coaching systems based on big data analytics, designed to provide coaches with decision support in three key areas: motion correction, training load monitoring, and tactical recommendations.

These efforts primarily focus on localized application scenarios, such as recognizing specific kicking techniques, managing classroom instruction in single sessions, or providing individual training feedback. However, they have yet to establish

a comprehensive framework that integrates the evolution of competition rules, the development of training systems, and the coordinated advancement of technical equipment and data platforms. In contrast, electronic protective gear and scoring systems in taekwondo and similar disciplines have become deeply integrated with competition regulations, forming an integrated solution that covers scoring, penalty decisions, and safety protection. This highlights the lag in sanda's development in areas like intelligent scoring, quantification of competitive behaviors, and data-driven training. Existing research tends to either emphasize narratives of traditional martial arts culture and project history or focus on isolated technical experiments, lacking systematic analysis that unifies the internal logic of "historical evolution—modern transformation—digitalization path." This gap precisely constitutes the key motivation for this study.

Addressing these limitations, this study bridges the gap between Sanda's traditional foundations and modern competitive practices by integrating digital technologies and smart sports perspectives, proposing an analytical framework of "From Traditional Martial Arts to Intelligent Competition". Specifically, the paper examines two key dimensions: First, it traces Sanda's evolution from military close-combat techniques and traditional martial arts combat skills into a regulated competitive sport, re-examining how its technical systems, competition structures, and training paradigms have been continuously redefined within national sports policies and global combat sports landscapes. Second, it systematically evaluates the latest applications of artificial intelligence, wearable sensors, virtual reality, and smart scoring systems in combat sports, analyzing their adaptability and limitations in Sanda scenarios. Based on these insights, the study proposes future-oriented digital development pathways and technical roadmaps for the sport.

This study addresses three core questions: First, how the evolutionary logic of Sanda's transformation from traditional martial arts to modern competitive sports lays the foundation for its digital transition; Second, what key bottlenecks in technical methods and governance structures currently hinder intelligent development in Sanda;

Third, how Sanda can establish a globally competitive intelligent competitive development path with local cultural characteristics by drawing on international digitalization experiences in combat sports. Through systematic analysis and theoretical integration of these three aspects, this paper aims to provide an analytical framework that combines historical depth with technological foresight for the high-quality development of martial arts Sanda in the digital sports era.

2 Historical Evolution of Sanda

The development of Sanda as a sport can be seen as a typical path of evolution from traditional Chinese martial arts to modern competitive combat sports. Initially, Sanda originated from unarmed combat and grappling techniques in traditional Chinese martial arts, taking root with the emergence of the concept of "Sanshou" during the Republican era and the trend toward practical combat training in martial arts schools. Historical records indicate that the "Sanda" sport "integrates various fist techniques, leg techniques, and grappling skills, synthesizing the five-thousand-year history of Chinese martial arts. Through the efforts of predecessors, it gradually established rules and evolved into the now widely recognized 'Sanda' sport."

After entering the new China, Sanda was promoted in the military and police system, becoming part of close combat and physical training. According to Wikipedia, "Sanda (Sandai) is a combat system initially developed by the Chinese military based on traditional martial arts and modern combat techniques," and this military and police training background laid the basic framework of Sanda for practical combat and integrated offense and defense.

With the advancement of sports system reform and the competitive development of martial arts, Sanshou has gradually shifted from military and police combat training to a national competitive sport. Since the 1980s, the national sports authorities have established unified competition rules, scoring systems, and training standards, promoting the standardization and institutionalization of Sanshou. Scholars have pointed out that "the evolution of martial arts Sanshou from traditional martial arts into China's modern combat techniques to compete with global combat sports makes its

development significant."

In this context, sanda has changed from the concept of "combat" to "competition" organization, and its technical content has also changed from pure fist, leg and throw to a system characterized by rules and structured training.

As illustrated in Figure 1, the evolution of Sanda (Chinese kickboxing) follows a non-linear trajectory rather than a simplified linear progression, progressing through multiple stages: traditional roots → militarization/police adaptation → competitive development → internationalization (see Figure 1 "Multi-stage Historical Evolution of Sanda"). Throughout this evolution, the technical system has continuously expanded: while early Sanda emphasized grappling and leg techniques, modern Sanda focuses on the "three-dimensional integration" approach—combining long-range kicks, close-range punches, and close-quarters takedowns—alongside advancements in scientific fitness training, systematic training cycles, and statistical analysis of techniques.

The historical evolution of Sanda reflects the deep integration of traditional martial arts combat spirit with modern competitive sports systems. From its earliest form of unregulated free combat to the modern integrated system combining punches, kicks, throws, holds, and takedowns, and now at the starting point of digital and intelligent development, Sanda has not only preserved its cultural roots but also gradually transformed into a globally competitive combat sport that meets the demands of sports industry development. Figure 1 visually illustrates this evolutionary path, establishing a theoretical framework for further exploration of its modern transformation and digital development in this study.

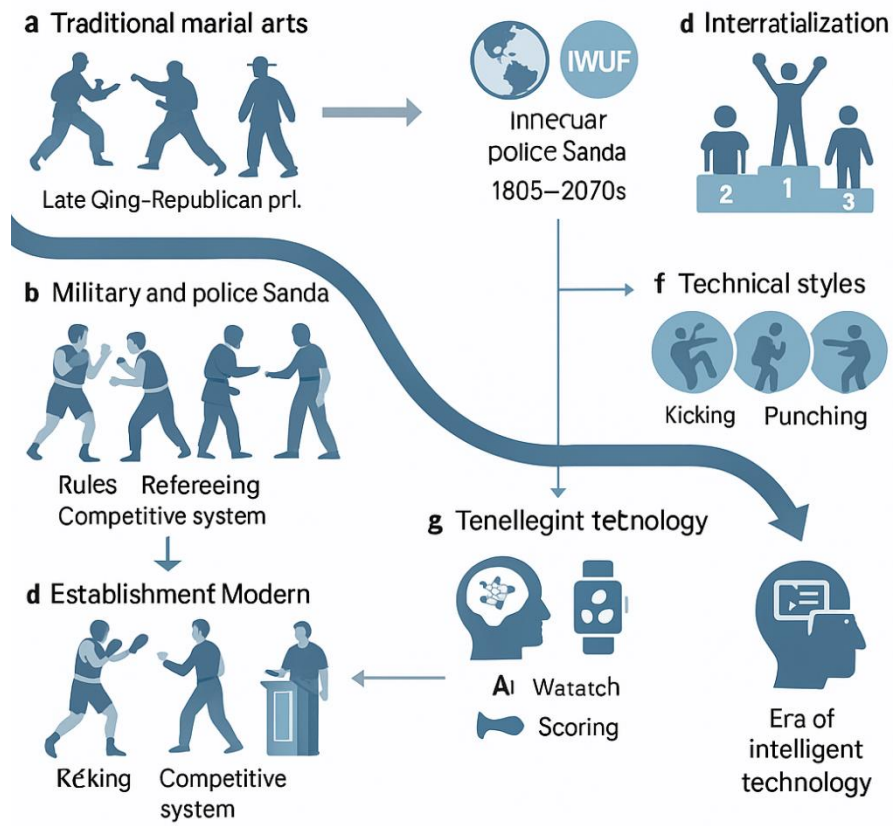


Table 1. Key Historical Stages and Institutional Transformations in the Development of Sanda

Historical Stage	Time Period	Key Institutional Context	Technical Characteristics	Regulations & System Changes	Representative Events / Documents
Traditional Martial Arts Foundations	Late Qing – 1930s	Traditional martial arts schools; folk martial associations	Emphasis on striking, kicking, qinna, and shuai techniques; practical combat focus	No unified rules; master-disciple oral transmission	Rise of martial arts groups; early “leitai” contests
Early “Sanshou/Scattered Hand” Concept Formation	1920s–1949	Central Guoshu Institute; provincial martial arts competitions	Systematization attempts of free-fighting forms; integration of various martial styles	Initial competition guidelines; separation of performance vs. combat events	1928 & 1933 national martial arts examinations
Military & Police Combat Stage	1950s–1970s	PLA combat training; Armed Police close-quarter combat curriculum	Practical defense & offense, wrestling-dominant; integration of bayonet and self-defense tactics	Beginning of unified CQB training standards	PLA Military Training Outline; police combat manuals
National Sports System Integration	1980–1989	State Sports Commission;	Systematic striking–	Drafting of first Sanda	1982–1989 national Sanda

		emergence of provincial Sanda teams	throwing integration; scientific training concepts introduced	competition rules; referee system established	invitational competitions
Modern Competitive Sanda Establishment	1990s	Formation of official national Sanda leagues	Enhancement of tactical system; standardization of scoring and venue	National Sanda Competition Rules (revised); introduction of weight classes	First National Sanda Championships; coaching certification system
Internationalization & Global Governance	2000–2010	International Wushu Federation (IWUF)	Standardized international judging; global athlete exchange	National Sanda Competition Rules (revised); introduction of weight classes; IWUF unified international rules; establishment of World Sanda Championships	World Sanda Championships (biennial since 2003)
Integration with Combat Sports Ecology	2005–2015	Cross-competition platforms (e.g., MMA, K-1)	Emphasis on multi-range transitions; strategic use of sweeps and throws	Adjustments to techniques allowed in competitions; harmonization with international combat culture	Sanda fighters entering global events; technical cross-fertilization
Scientific Training & Performance Analysis Era	2010–2020	Sports science institutions; national training centers	Advanced strength & conditioning; biomechanics-guided striking	Monitoring systems for loads, HRV, injury prevention; periodization frameworks	National sports science research reports; wearables in training
Digitalization & Intelligent Technology Stage	2020–present	AI-based sports tech industries; smart training laboratories	AI motion capture, inertial sensors, VR sparring; data-driven technical analysis	Exploration of intelligent scoring, automated judging; standardized digital metrics	Establishment of smart Sanda platforms; pilot AI judging projects

3 Modern Transformation of Sanda

The evolution of modern Sanshou embodies the dynamic interplay between traditional martial arts combat philosophies, military combat systems, and contemporary sports science. As the sports industry modernizes, training methodologies advance, and global demand for martial arts grows, Sanshou has undergone a systematic transformation from cultural heritage to modern athletic discipline. This chapter systematically examines Sanshou's modernization through four key dimensions: rule system modernization, scientific training methodologies, sport-

oriented technical styles, and enhanced psychological-tactical frameworks.

From a regulatory framework perspective, modern Sanshou has evolved from the relatively informal combat practices of traditional "bare-handed fighting" into a competitive sport with clearly defined institutional boundaries, quantifiable scoring metrics, and standardized competition environments. The modern Sanshou rules system not only standardizes competition venues, time structures, scoring mechanisms, and violation judgments, but also significantly reduces competition risks through safety equipment and medical supervision protocols. Table 2 highlights the fundamental institutional differences between the two: Traditional martial arts competitions often rely on sectarian or regional rules lacking unified judging procedures and quantifiable standards, while modern Sanshou operates under unified standards established by the General Administration of Sport of China and the International Wushu Federation. Official regulations explicitly define criteria such as strike effectiveness, scoring for grappling techniques, and control of competition zones. This highly institutionalized regulatory system not only enhances fairness in competitions but also promotes data-driven and quantifiable management in sports training, ultimately establishing Sanshou as a modern combat sport that meets international sporting event requirements.

Table 2. Comparative Analysis of Modern Sanda Competition Rules and Classical Martial Arts Rule

Systems			
Dimension	Modern Sanda Competition Rules	Classical Martial Arts Rule Systems (Traditional Leitai / School Rules)	Implications for Sportization and Evaluation
Primary objective	Standardized full-contact sport emphasizing fairness, safety and performance ranking	Practical combat efficiency, protection of school reputation, often linked to self-defense or honor	Modern Sanda prioritizes measurable performance; classical systems focus on survival and prestige
Rule codification	Written national and international rulebooks, periodically revised by sport authorities	Semi-formal or oral rules, varying by lineage, region or organizer	High codification enables multi-center tournaments and long-term statistics
Match area	Fixed platform or ring with specified dimensions and safety zone	Leitai, courtyard, or open space; size and elevation highly variable	Standardized area supports TV broadcasting and analytics
Match duration & rounds	Fixed rounds (e.g., 3 × 2 min) with regulated rest intervals	Flexible or undefined duration; bouts may	Time structure facilitates conditioning planning and pacing strategies

Dimension	Modern Sanda Competition Rules	Classical Martial Arts Rule Systems (Traditional Leitai / School Rules)	Implications for Sportization and Evaluation
		continue “until clear dominance”	
Weight classes	Multiple weight categories with strict weigh-in procedures	Typically no formal weight divisions; size differences accepted as part of “real combat”	Weight classification improves fairness and reduces injury risk
Scoring criteria	Point system based on clean strikes, effective throws, ring-out, knockdowns, etc., with detailed definitions	Dominance judged holistically by referees or elders; emphasis on visible control or injury	Sanda scoring is more granular and reproducible for quantitative analysis
Permitted techniques	Regulated set of punches, kicks, sweeps and throws; techniques catalogued and demonstrated in rulebook	Highly diverse; content depends on style (e.g., qinna, joint breaks, dim-mak)	Modern rule set narrows the repertoire but improves comparability
Prohibited techniques	Deliberate attacks to eyes, throat, groin, spine; small-joint manipulations; ground striking, etc.	Fewer explicit prohibitions; some lineages allow joint locks, chokes, or weapon transitions	Modern bans maximize safety but partially detach from “lethal” combat logic
Protective equipment	Mandatory gloves, headgear, mouthguard, groin guard, chest protector in amateur level	Minimal or no protective gear; sometimes simple cloth wraps	Protective gear shifts focus from survival to scoring volume and technical diversity
Refereeing system	Central referee + multiple judges; use of electronic scoring and video review in some events	Single referee or senior master; decisions may be final and not reviewable	Multi-judge system reduces individual bias and allows dispute resolution
Victory conditions	Points decision, technical knockout (TKO), knockout (KO), or opponent disqualification	Yielding, being unable to continue, being thrown off leitai, or decision by elders	Modern conditions emphasize standardized medical stoppage and recordable outcomes
Penalty mechanism	Structured warnings, point deductions and disqualifications with documented criteria	Informal warnings, immediate stoppage, or even expulsion from school	Formalized penalties create transparent incentive structures for athletes
Training paradigm alignment	Periodized training with sports science support; emphasis on repeated competition scenarios matching rule set	Broad curriculum including forms, weapons and internal work; sparring may not strictly follow uniform rules	Sanda training is tightly coupled to competition metrics, enabling performance optimization
Medical & safety protocols	Pre-fight medical checks, ringside physicians, concussion protocols, injury surveillance	Historically limited; post-injury treatment based on traditional medicine or ad-hoc decisions	Modern protocols reduce severe injuries and support long-term athlete management
Commercialization & media compatibility	Designed for broadcast: clear rounds, visible scoring moments,	Spectacle exists but lacks standardized format for modern media	Rule design of Sanda increases audience understanding and commercial value

Dimension	Modern Sanda Competition Rules	Classical Martial Arts Rule Systems (Traditional Leitai / School Rules)	Implications for Sportization and Evaluation
Institutional governance	dramatic throws and ring-outs Governed by national sports commissions and IWUF; unified certification for coaches and referees	Controlled by clans, associations or local organizers; authority diffused	Central governance promotes global dissemination and Olympic-style management

Secondly, from the perspective of training systems, modern sanda training has completely departed from the traditional martial arts approach that relied on master-apprentice relationships and experience, shifting to a sports science-driven cyclical training structure. Table 3 clearly demonstrates the scientific planning model of modern sanda training from macrocycle, mesocycle to microcycle. In this model, training is no longer a simple accumulation of strength, technique, or endurance, but rather a rational arrangement of physical peak performance through cyclical operations. The preparation phase emphasizes building physical foundations, such as maximum strength, basic aerobic capacity, and foundational technical proficiency. During the specialized phase, training focuses shifts to speed, specialized strength (e.g., striking power), agility, and combat strategies. The pre-competition phase prioritizes simulated real combat, targeted tactical optimization, and weight management. The recovery phase focuses on repairing the nervous system and preventing sports injuries. Cyclical training enables more precise load regulation in sanda, allowing athletes to achieve peak performance in critical competitions.

Table 3. Periodization Model of Modern Sanda Training (Weekly, Monthly, and Cyclical Phases)

Periodization Level	Training Phase	Duration	Primary Training Objectives	Typical Training Content
Macrocycle	Annual Competitive Plan	10–12 months	Long-term performance development; preparation for national/international competitions	Sequential arrangement of preparatory, pre-competition, competition, and transition phases
	Preparatory Phase	6–12 weeks	Build foundational strength and aerobic base; improve movement quality	Strength training, long-distance running, technical fundamentals, flexibility
Mesocycle	Pre-competition Phase	4–8 weeks	Enhance specific power, speed, tactical execution	High-intensity interval training (HIIT), pad work, tactical drills, controlled sparring
	Competition Phase	2–6 weeks	Peak performance, tactical refinement, weight management	Simulation bouts, strategy sessions, reaction-speed drills, video analysis

Periodization Level	Training Phase	Duration	Primary Training Objectives	Typical Training Content
	Transition (Recovery) Phase	2–4 weeks	Physical and psychological recovery; injury prevention	Light aerobic training, mobility work, rehabilitation exercises
Microcycle	Weekly Cycle	5–7 days	Balanced integration of strength, technique, and recovery	Strength (2–3 sessions), technique (3–5 sessions), sparring (1–2 sessions), rest (1–2 days)
Training Session	Daily Session	1–3 hours	Specific skill acquisition, conditioning stimulus, or restoration	Warm-up → technical drills → conditioning → cool-down

At the core of modern sanda training, five fundamental competencies are prioritized: power, speed, reaction, tactics, and mental resilience. Figure 2 (Modern Training System Architecture) visually demonstrates how these multidimensional capabilities synergize. Power forms the foundation for striking force, grappling control, and physical confrontation. Speed determines movement efficiency, combo execution pace, and offensive-defense rhythm. Reaction capability directly impacts decision-making efficiency in fast-paced combat scenarios. Tactical dimensions encompass spatial control, rhythm adjustment, offensive diversion, and defensive counterattacks. Mental resilience significantly influences competitive stress management, focus concentration, and on-the-spot response. Unlike traditional martial arts that emphasize "intention, breath, and power" as core training principles, modern sanda employs quantifiable metrics (such as striking speed, reaction time, and peak force) to monitor these dimensions, transforming abstract competency frameworks into measurable, trainable, and assessable scientific systems.

The evolution of modern Sanshou is also characterized by its sport-oriented technical style. While maintaining the traditional "three-in-one" system (kicking, striking, and grappling), contemporary matches feature faster pacing, streamlined techniques, and strategic applications. Kicking techniques primarily include side kicks, whip kicks, and front kicks, while punching techniques emphasize straight punches, side punches, and combinations. Grappling emphasizes rapid clinching, positional control, and counterattacks. Guided by competition rules, athletes often adopt a strategic framework of "impact scoring—territory control—rhythm suppression,"

which contrasts sharply with the traditional martial arts' emphasis on "diverse combat techniques." The technical evolution of modern Sanshou reflects the logic of competitive sports: efficiency, stability, and repeatability.

The integration of training technology has significantly accelerated the modernization of Sanda. By leveraging advanced tools like video analysis, motion capture, muscle strength assessments, and combat data analytics, coaches can now precisely evaluate athletes' technical execution, identify movement flaws, and analyze tactical decision-making patterns. Modern competitive Sanda training has progressively incorporated auxiliary systems including electronic protective gear testing, reaction targets, impact force monitors, and wearable devices, transforming training from experience-based to evidence-driven.

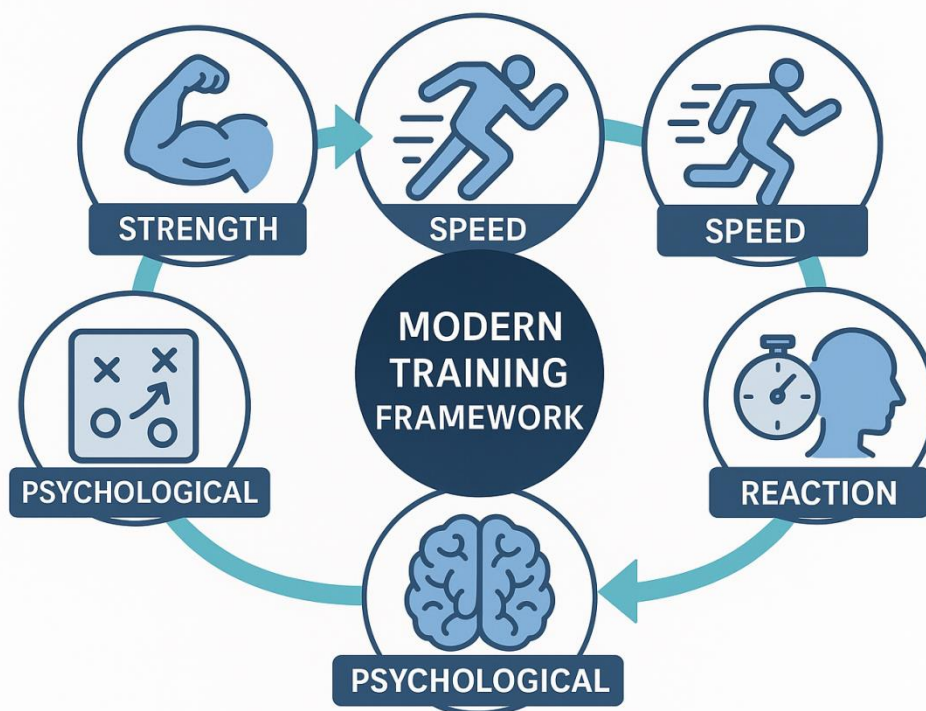


Figure 2. Integrated Modern Training Framework for Sanda: Strength–Speed–Reaction–Tactical–
Psychological Model

The modern transformation of Sanda has undergone comprehensive reshaping across multiple dimensions, including rule systems, training frameworks, technical methodologies, and psychological tactics. As demonstrated by the institutionalization,

scientific rigor, and systematic logic in Table 2, Table 3, and Figure 2, Sanda has evolved beyond its traditional martial arts roots to become a highly professionalized combat sport that meets international standards and aligns with modern athletic development. This transformation not only elevates Sanda's competitive level but also lays a solid foundation for its future advancement into digital and intelligent domains.

4 Digital Transformation of Sanda

With the rapid advancement of technologies such as artificial intelligence, sports biomechanics, wearable sensors, and virtual reality (VR/XR), the sport of Sanda is undergoing a profound digital transformation. The traditional training model, which primarily relied on experience and master-apprentice inheritance, is transitioning into a modern sports technology system driven by data, systematic, and intelligent. This chapter systematically explores the pathways and logic of Sanda's digital development through four key aspects: technology integration, intelligent training processes, digitalized referee systems, and the construction of smart ecosystems.

From a technical perspective, the training and management systems of Sanshou have progressively integrated digital tools across multiple operational phases. As shown in Table 4, current Sanshou training encompasses various technological modules including motion capture systems, wearable smart devices, AI scoring platforms, physiological monitoring systems, tactical visualization tools, and intelligent venue equipment. Among these, IMU inertial sensors, OpenPose-based posture recognition systems, and smart strike measurement devices have been implemented in national teams and select provincial squads. Meanwhile, VR-based combat simulations, XR mixed reality training, and automated referee systems remain in the pilot implementation phase. These technologies share a common characteristic: they establish a cyclical training framework through "real-time measurement—quantitative feedback—training optimization," transforming the previously subjectively assessed training process into evidence-based decision-making.

Table 4. Applied and Potential Digital Technologies in Sanda Training, Judging, and Performance

Analytics

Technology Category	Specific Technology / Tool	Application Scenario in Sanda	Function / Advantage	Current Status
Motion Capture & Biomechanics	2D/3D Computer Vision Systems (OpenPose, MediaPipe)	Technique analysis; posture correction	Detect joint angles, trajectories, strike kinematics	Early-stage adoption; lab-tested
	Optical Motion Capture (Vicon, Qualisys)	Biomechanical assessment; kick/punch velocity measurement	High-precision motion tracking	Used in academic studies, not in field
	Inertial Measurement Units (IMU sensors)	On-body tracking during sparring	Real-time acceleration, rotation, impact load	Partial application in training
Wearable Performance Monitoring	Smart Gloves with Force Sensors	Punch force and frequency measurement	Quantifies striking intensity and symmetry	Commercial prototypes available
	Smart Kicking Pads / Impact Sensors	Kick impact detection	Measures peak force and contact quality	Widely used in taekwondo; potential for sanda
	Heart Rate Variability (HRV) Sensors	Recovery monitoring	Tracks fatigue, autonomic balance	Common in elite training
AI-assisted Judging & Scoring	GPS/Indoor Positioning Tags	Spatial movement analysis	Tracks distance, angles, zone control	Potential application
	Automated Scoring Algorithms (CV-Based)	Competition refereeing	Classifies legal strikes, counts hits	Under experimental testing
	Impact Recognition AI	Foul detection; illegal hits	Reduces subjective refereeing errors	Early development
Video Analysis & Tactical Analytics	Intelligent Rule Engine	Match decision support	Ensures rule consistency	Planned for future
	High-Speed Video + AI Tagging	Match review & tactical modeling	Identifies patterns, reaction timings	Widely used internationally
	Hawk-Eye-like Multi-Camera System	Real-time decision verification	Ring-out, knockdown verification	Potential application
Physiological & Neuromuscular Monitoring	EMG Surface Sensors	Muscle activation timing	Assesses technique efficiency	Used in research
	Lactate & Metabolic Analyzers	High-intensity interval monitoring	Determines athlete conditioning level	Common in elite labs
	Force Platform	Balance, stance stability	Measures ground reaction force (GRF)	Lab-based equipment
Virtual Reality (VR) / Extended Reality (XR)	VR Sparring Simulator	Reaction, decision-making drills	Safe tactical scenario training	Under pilot development

Digital Training Platforms	XR Mixed-Reality Combat Training	Technique learning and feedback overlay	Provides holographic cues	Potential application
	Athlete Performance Database	Long-term athlete management	Tracks match logs, biometrics, training loads	Implemented in national teams
	Cloud-Based Coaching System	Remote coaching & analytics	Supports distributed athlete training	Increasingly adopted
Medical & Injury Surveillance Systems	AI Injury Prediction Models	Preventive sports medicine	Predicts overuse or impact injuries	Emerging research
	Digital Concussion Detection Tools	Head impact monitoring	Identifies high-risk events	Potential use in sanda
Smart Arenas & Equipment	Intelligent Ring Edge Sensors	Detect ring-out, boundary control	Enhances officiating accuracy	Prototype-level
	Smart Protective Gear	Integrated IMU + pressure sensor	Real-time hit detection	Under testing for combat sports

Artificial intelligence (AI) is revolutionizing the framework for Sanshou (Chinese martial arts) technique recognition and performance evaluation. By leveraging computer vision and deep learning algorithms, practitioners' movements can be translated into critical metrics like skeletal point coordinates, peak force measurements, and reaction time sequences. Table 5 reveals distinct model performance in Sanshou technique identification: HRNet achieves the highest accuracy rate of 92.8%, making it ideal for scientific research and high-precision applications, while MediaPipe and MoveNet, with their faster processing speeds, excel at real-time feedback during training sessions. AlphaPose maintains 90.1% recognition accuracy even under occlusion conditions, demonstrating its suitability for Sanshou's fast-paced combat dynamics and frequent body contact. Consequently, AI-based posture recognition technology not only replaces manual video analysis but also provides quantitative deviation data, offering scientific foundations for technique correction, movement optimization, and injury risk prediction.

Table 5. Accuracy Comparison of AI Pose Recognition Systems in Sanda Training

Pose Recognition System	Model Type	Key Features	Accuracy in Sanda Technique Detection (%)	Real-Time Performance	Suitability for Sanda Training
-------------------------	------------	--------------	---	-----------------------	--------------------------------

OpenPose	2D Multi-Person Pose Estimation	Full-body keypoints; multi-camera support	87.30%	Moderate	Suitable for technical analysis and offline review
MediaPipe Pose	Lightweight 2D Pose Model	High-speed inference; mobile deployment	82.50%	High	Suitable for daily training and quick feedback
AlphaPose	High-precision 2D Pose Tracking	Strong multi-object tracking; stable under occlusion	90.10%	Medium	Effective for sparring scenarios with partial occlusion
HRNet	High-Resolution Network	Preserves spatial resolution; strong accuracy	92.80%	Low–Medium	Suitable for scientific research, less ideal for real-time
MoveNet Thunder	High-speed 2D Pose Model	Optimized for speed; mobile/edge devices	84.60%	Very High	Good for rapid training feedback and mobile applications
DeepLabCut	Markerless Tracking	High precision for limb trajectories	89.40%	Low	More suitable for biomechanics labs
OpenPifPaf	Joint detection + field representation	Good robustness under motion blur	86.70%	Medium	Applicable to high-speed kicking/punching recognition

The essence of digitalization lies not in isolated technology stacking, but in building a synergistic intelligent training ecosystem. Figure 3 illustrates the architecture of the intelligent sanda system, progressing from foundational data collection (motion capture devices, smart protective gear, physiological sensors) through mid-level data processing and analysis (AI posture recognition, strike force modeling, tactical visualization systems) to upper-layer application modules (intelligent training feedback, automated scoring, injury monitoring, cloud-based competitive strategy analysis). This framework establishes a closed-loop system of "athlete-coach-system-data", transforming traditional linear training processes into real-time dynamic control systems. The core advantage of this intelligent ecosystem is its ability to integrate all training data, creating athlete "digital profiles" through long-term longitudinal tracking. This enables personalized training, cyclical load management, and game strategy formulation.

In training, digitalization has significantly advanced the methodology of Sanda (Chinese kickboxing) training. Unlike traditional methods that relied on coaches' visual

judgment of technique execution, digital systems now provide quantitative feedback through metrics like force curves during strikes, reaction time, footwork patterns, and heart rate changes. For instance, smart punching targets record punching speed, force, and angle; AI-powered tactical analysis tracks success rates, offensive frequency, and spatial control during sparring; while physiological monitoring systems assess recovery status, fatigue levels, and stress indices. This data-driven approach enables more rational and personalized training load planning.

In terms of competition officiating, digitalization has enhanced the international appeal of Sanda. AI recognition technology assists in evaluating hit validity, illegal strikes, and out-of-bounds calls, reducing human errors and improving fairness. Meanwhile, multi-camera systems enable Hawk-Eye-like 'technical replay reviews,' boosting the credibility of major tournaments.

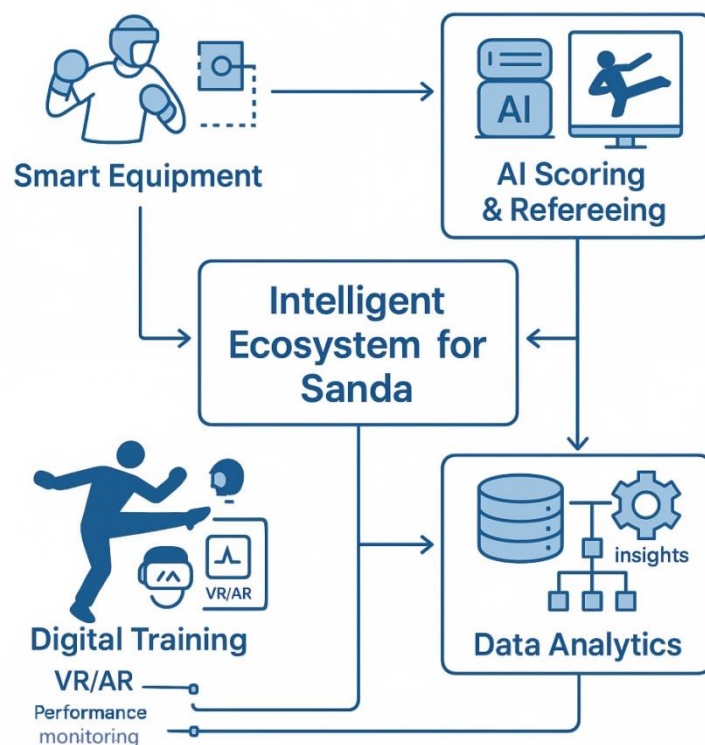


Figure 3. Intelligent Sanda Ecosystem Architecture

5 Comparative Analysis

The digital transformation of Sanda (Chinese kickboxing) is advancing rapidly yet remains underdeveloped. Compared to mainstream international combat sports, it still lags behind in three key areas: technical framework architecture, data governance capabilities, and digitalization of training methodologies. A comparative analysis reveals distinct characteristics: progressive enhancement in training systems, relatively weaker competitive frameworks, and an ecosystem still in its formative stages. By benchmarking against Taekwondo, boxing, Mixed Martial Arts (MMA), and fencing, we can clearly identify both the strengths and structural weaknesses in Sanda's digital evolution.

From the perspective of electronic scoring and sensor systems, Sanda remains in its pilot phase with no internationally unified sensor evaluation standards established. In contrast, Taekwondo and fencing have developed mature electronic protective gear and sensing systems that can objectively identify valid hits and enable rapid decision-making. Currently, Sanda's judging system still heavily relies on human judgment. To advance the sport, increased R&D investment is needed in areas such as impact sensing technology, pressure detection systems, and smart protective gear.

While Sanda has implemented video replay systems in major competitions, its rules, equipment, and referee training standards remain non-internationalized. In contrast, sports like Taekwondo, boxing, and MMA have established systematic video replay protocols that reduce misjudgments and enhance credibility. This highlights the need for Sanda to develop a unified international framework of "challenge-review-final adjudication" and promote standardized digital refereeing systems.

In digital training, Sanda has established foundational capabilities including heart rate monitoring, IMU inertial sensors, and impact force measurement devices. However, its application remains limited to national teams and select provincial squads. In contrast, MMA training systems demonstrate significantly more mature advancements in biomechanical monitoring, motion analysis, and recovery management. To achieve scientific training in Sanda, it is essential to strengthen long-term data management,

implement real-time training load monitoring, and establish intelligent feedback mechanisms.

In the fields of AI and tactical data analysis, Sanda's applications are primarily confined to research, lacking practical systems for coaches and athletes. Table 6 clearly shows that MMA and Taekwondo have established comprehensive data analysis ecosystems, including key metrics like strike frequency, movement patterns, and control duration. Moving forward, Sanda needs to achieve productization and standardization in AI-powered motion recognition, tactical modeling, and match data extraction.

As shown in Table 6, Sanda lags behind sports like Taekwondo, MMA, and fencing in overall digital maturity, particularly in electronic scoring systems, smart venue infrastructure, tactical data platforms, and injury monitoring technologies. However, Sanda demonstrates exceptional digital potential in technical complexity, competitive intensity, and skill diversity, making it particularly suitable for adopting AI-powered posture recognition, multimodal sensor fusion, and intelligent tactical modeling. This digital lag stems not from technical limitations, but rather from underdeveloped industry standards, inadequate data governance frameworks, and immature application ecosystems. Once a systematic advancement mechanism is established, Sanda's digital acceleration potential will become remarkably significant.

Table 6. Comparative Digital Maturity of Sanda and Other Combat Sports

Dimension	Sanda	Olympic Taekwondo (WT)	Olympic Boxing	Mixed Martial Arts (MMA)	Fencing	Remarks / Implications
Electronic Scoring & Sensor-Based Judging	Pilot-stage trials of smart gloves and kicking pads; no unified international system	Fully implemented electronic body/foot protectors with pressure sensors; core of scoring system	Limited sensor integration; scoring mainly by judges and computer entry	Experimental use of glove sensors or mat sensors in selected events	Long-standing use of electric scoring apparatus for valid touches	Taekwondo and fencing lead in sensor maturity; Sanda remains exploratory
Video Replay & Challenge System	Used in selected elite events; rules lack global standardization	Mature coach challenge and video	Video confirmation used in	Multi-angle replay commonly used in top	Video replay supports judgment of	Sanda must standardize replay rules for

Dimension	Sanda	Olympic Taekwondo (WT)	Olympic Boxing	Mixed Martial Arts (MMA)	Fencing	Remarks / Implications
		replay system widely applied in Olympics and Worlds	Olympic-level bouts	promotions (e.g., UFC)	valid touches and fouls	international consistency
Wearable Performance Monitoring in Training	Heart-rate belts, IMUs, and impact sensors used by national/provincial teams	Widely used HR, GPS/IMU, and load monitoring systems	HR and impact monitoring increasingly common	Extensive use of wearables and athlete management platforms	Growing use of wearables in training settings	MMA and WT have more mature system-level integration; Sanda is transitioning
AI-Based Technique & Pose Analysis	Mainly used in academic and research contexts; limited commercial platforms	Commercial kicking-analysis apps widely available	AI motion analysis under development; limited adoption	Some clubs use third-party AI analytics for striking and movement	AI used for technical breakdown and match statistics	Sanda's AI application remains early-stage and research-driven
Tactical & Match Data Analytics	Fragmented adoption; some teams build internal data systems	High-level teams routinely use match analytics software tracking scoring zones, timing, patterns	International federations use standardized match data; adoption varies across nations	Top MMA promotions utilize advanced stats (striking rate, control time, grappling metrics)	Uses structured bout records, touch patterns, scoring tendencies	MMA and WT lead in tactical analytics; Sanda still developing structured systems
Smart Venue & Edge Computing	Limited trials of edge sensors (e.g., ring-boundary detection)	Use of electronic mats and boundary sensors in major events	Traditional ring; limited smart venue elements	Use of high-definition multi-camera systems; limited smart floors	Highly electronic weapon-target communication system	Sanda needs development in smart venue hardware integration
Medical & Injury Surveillance Digitalization	Mostly manual documentation; limited integration with load monitoring	Some federations maintain digital injury and load databases	Emerging digital concussion and injury tracking tools	Strong medical databases in elite leagues; head-impact tracking common	Medical data usage varies; often internal to associations	Crucial for head-impact sports; Sanda requires digital injury protocols
Virtual / Augmented Reality (VR/XR) Training	Concept-stage or small pilot trials	Early VR training products for kicking and scenario learning	VR used mainly for research and cognitive studies	Limited but growing interest in VR for tactical simulations	Minimal VR usage; mainly for demonstrations	Sanda has high potential for immersive VR-based tactical training
Data Governance & Longitudinal	Limited long-term athlete data systems; some national teams exploring	Well-established longitudinal data across	In progress; federations building larger unified databases	Top MMA promotions manage comprehensive	Varies; structured but often not open-access	Sanda lacks unified global data governance

Dimension	Sanda	Olympic Taekwondo (WT)	Olympic Boxing	Mixed Martial Arts (MMA)	Fencing	Remarks / Implications
Athlete Profiling	centralized platforms	Olympic cycles		performance databases		for athlete tracking

Conclusion

This study systematically reviews the historical evolution of Sanda's transition from traditional martial arts to modern competitive sports, while analyzing the systemic innovation pathways in technical training, competition management, and performance analysis driven by digitalization. Historical development reveals that Sanda gradually transitioned from empirical practices to scientific approaches in establishing rule systems, competitive standards, and training models. The modern transformation manifests through the construction of high-performance training systems encompassing strength, speed, reaction, tactics, and psychological aspects. Compared with digital practices in mature combat sports like Taekwondo, Boxing, and MMA, Sanda still lags significantly in electronic scoring systems, long-term data governance, injury monitoring, and tactical analysis. However, Sanda's inherent technical diversity and complex offensive-defensive structures naturally align with digital tools, offering substantial potential for intelligent development. The proposed intelligent ecosystem framework provides a reference for establishing an integrated training-competition-monitoring system in Sanda's future. In summary, Sanda's digitalization is not a marginal improvement but a systematic project reshaping training paradigms, enhancing competitive fairness, and promoting internationalization. With the maturation and standardization of technical systems, Sanda is poised to enter the era of intelligent competition, achieving comprehensive scientific and global development.

Reference

1. Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine*, 38(12), 1025–1043.
2. Biau, D. J., & Kern is, S. (2020). Real-time video replay in combat sports:

Applications and limitations. *Journal of Sports Sciences*, 38(4), 455–463.

3. Błaszczyszyn, M., Szczęśna, A., & Pawlyta, M. (2021). Wearable sensors in martial arts: A systematic review. *Sensors*, 21(2), 589.
4. Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. Camomilla, V., Bergamini, E., Fantozzi, S., & Vannozzi, G. (2018). Trends supporting the in-field use of wearable inertial sensors for sport performance evaluation. *Frontiers in Bioengineering and Biotechnology*, 6, 175.
5. Chambet, M., Blache, Y., & Monteil, K. Chambet, M., Blache, Y., & Monteil, K. (2022). Monitoring impact forces in combat sports using IMU systems. *Measurement*, 191, 110786.
6. Chen, J., & Zhang, L. Chen, J., & Zhang, L. (2021). Artificial intelligence in combat sports training: A review. *IEEE Access*, 9, 112312–112329.
7. Estevan, I., & Falco, C. Estevan, I., & Falco, C. (2013). Influence of Olympic weight categories on performance in taekwondo. *Journal of Strength and Conditioning Research*, 27(2), 305–312.
8. Figueroa, P. J., Leite, N. J., & Barros, R. M. L. Figueroa, P. J., Leite, N. J., & Barros, R. M. L. (2006). Tracking soccer players using the graph representation of context. *Pattern Recognition Letters*, 27(7), 757–767.
9. Fukuda, D. H., & Signorile, J. F. Fukuda, D. H., & Signorile, J. F. (2019). Biomechanics and performance determinants in striking combat sports. *Sports Biomechanics*, 18(4), 391–409.
10. Ishii, T., Murata, M., & Maeda, K. Ishii, T., Murata, M., & Maeda, K. (2020). AI-based pose estimation for evaluating martial arts techniques. *Sensors*, 20(21), 6285.
11. James, N., & Silva, M. James, N., & Silva, M. (2016). Video analysis and performance indicators in combat sports. *International Journal of Performance Analysis in Sport*, 16(1), 470–486.
12. Krzysztof, M., & Włodzimierz, S. Krzysztof, M., & Włodzimierz, S. (2012).

- Special judo fitness test—Recommendations for training. *Archives of Budo*, 8(1), 21–27.
13. Leong, H. T., et al. (2018). Applications of wearable sensors in combat sports performance analysis. *Procedia Engineering*, 147, 131–137.
 14. Li, R., Pan, J., & Xu, W. (2021). Virtual reality-based tactical simulation for martial arts. *Computers in Human Behavior*, 125, 106959.
 15. Marinsek, M. (2021). Biomechanics of kicking techniques in martial arts: A systematic review. *Sports Biomechanics*, 20(4), 453–475.
 16. Moenig, U. (2015). The evolution of taekwondo competition rules and their impact on the sport. *Asia Pacific Journal of Sport and Social Science*, 4(3), 198–213.
 17. Müller, C., & Brand, R. (2020). Psychological load monitoring in elite combat sports. *European Journal of Sport Science*, 20(3), 400–409.
 18. O' Donovan, D., et al. (2020). Real-time athlete monitoring in high-intensity sports: A review. *Journal of Sports Sciences*, 38(14), 1597–1608.
 19. Oliveira, T., & Ribeiro, J. (2019). Performance indicators in mixed martial arts: Technical–tactical analysis. *International Journal of Performance Analysis in Sport*, 19(2), 267–284.
 20. Pfau, T., & Ferrari, M. (2021). Smart arenas and edge computing for real-time sports analytics. *Sensors*, 21(8), 2745.
 21. Pueo, B. (2016). High-speed cameras for motion analysis in sport. *Journal of Human Kinetics*, 53, 1–10.
 22. Raab, M., & Araújo, D. (2019). Embodied cognition in combat sports: Decision-making and perception–action coupling. *Psychology of Sport and Exercise*, 43, 110–117.

23. Rossi, A., et al. (2020). Wearable heart-rate sensors for training load monitoring in striking sports. *Frontiers in Physiology*, 11, 561.
24. Smith, R., Draper, C., & Potts, J. Smith, R., Draper, C., & Potts, J. (2018). Contact force measurement technologies for combat sports. *Sports Engineering*, 21(3), 213–222.
25. Torres, C., & Coimbra, R. Torres, C., & Coimbra, R. (2022). Athlete digital profiling and longitudinal tracking systems in elite sports. *Sports Medicine*, 52, 155–170.
26. Yoo, J. H., & Kim, S. Yoo, J. H., & Kim, S. (2019). Scoring patterns and electronic protectors in taekwondo: A performance analysis. *PLoS ONE*, 14(5), e0216509.