Practice and Application of Ski Simulator

Qianrui Guo[1], Rongrong Yin[1*], Zhiyong Zhang[2]

[1]School of Physical Education and Sports Science, Xi' an Physical Education University, Xi'an, 710068, China.
[2]Engineering Research Center of Innovative Technology of Intelligent Sports Equipment, Universities of Shaanxi Province, Xi'an, 710068, China.
[*]Corresponding author:2018023@tea.xaipe.edu.cn

Abstract: *Driven by the dual forces of the popularization of skiing and the intelligent development of sports, the ski simulator, as a core piece of equipment that overcomes the limitations of outdoor ski venues and weather conditions, has gradually moved from theoretical research to practical application, playing an important role in areas such as ski teaching, professional training, and public entertainment. Based on the current practical application status of ski simulators, this paper systematically elaborates the practical solutions for its hardware configuration and software implementation, analyzes its application modes, practical effects, and core advantages in different scenarios, identifies the problems existing in the application process through existing case studies, and proposes targeted optimization strategies. This paper provides practical references and theoretical support for the large-scale practical application and technological upgrading of ski simulators, thereby contributing to the nationwide popularization and high-quality development of ice and snow sports.*

Keywords: *ski simulator; practical application; motion capture; scene adaptation; ice and snow sports.*

Introduction

As a winter sport that combines competitiveness and entertainment, skiing has seen its popularity steadily increase in China in recent years. However, outdoor ski training is constrained by factors such as natural conditions, venue costs, and safety risks, which severely limit the promotion of skiing and the improvement of training quality. With the rapid development of virtual reality (VR) technology, artificial intelligence, and sensor technology, the ski simulator has achieved a transition from theoretical design to practical application. By means of precise motion capture, realistic scene simulation, and scientific feedback guidance, the ski simulator effectively compensates for the shortcomings of outdoor skiing and serves as an important bridge connecting theoretical ski instruction and practical training. At present, various types of ski simulators have been implemented and applied both domestically and internationally. For example, the Joyful World Double-Plank Ski Simulator System has been successfully used in schools, gyms, enterprises, and other settings, and it has been selected as an outstanding creative design solution for the "Technology Winter Olympics Smart Beijing" initiative, demonstrating broad prospects for practical application. Based on current practical application cases and technological implementation experience of ski simulators, this paper systematically reviews their current status of practice and application from the perspectives of hardware configuration, software implementation, multi-scenario application, practical problems, and optimization strategies, thereby providing support for subsequent technological optimization and scenario expansion.

1. Practical configuration scheme of the ski simulator

Based on the current practical implementation experience of ski simulators, and taking into account application effects, cost control, and scene adaptability, a standardized hardware configuration and software implementation scheme has been developed. Different from purely theoretical designs, all configurations have been validated through practice, meeting the application needs of different scenarios while reserving space for upgrades to adapt to subsequent technological iterations. The hardware adopts a modular configuration, and the software is implemented based on existing mature algorithms, ensuring stable equipment operation and convenient operation, thus meeting the core requirements of practical application scenarios[1].

1.1 Hardware Practice Configuration

The hardware configuration takes "precise acquisition, stable operation, and scene adaptation" as its core. It optimizes component selection based on practical application feedback, avoids redundant configuration, and balances performance with cost-effectiveness. It has been verified in multiple implementation cases and is suitable for diverse scenarios such as physical education, fitness, and entertainment.

1.1.1 Inertial measurement unit

In practice, the MPU9250 inertial measurement unit is adopted, which integrates a three-axis accelerometer, a three-axis gyroscope, and a three-axis magnetometer. It can collect the skier's angular velocity, acceleration, limb attitude angles, and magnetic field data in real time, accurately capturing motion trajectories such as gliding, turning, braking, and jumping, thereby effectively avoiding the errors of a single inertial measurement. This module features fast response speed and high measurement accuracy, and it can capture millisecond-level motion changes. Verified through practice, it meets the motion capture needs of skiers at different skill levels, providing core data support for motion feedback and optimization, and is suitable for professional training and teaching guidance scenarios[2].

1.1.2 Pressure sensing module

Multiple FSR402 film pressure sensors are embedded in the simulated sliding platform, and their layout is optimized through practical debugging. The module can monitor the pressure distribution, force magnitude, and center-of-gravity shift of the skier's feet on the platform in real time and with high precision. By analyzing the pressure data, it can determine the skier's force exertion method and center-of-gravity control accuracy, providing a quantitative reference for motion optimization. At the same time, it drives the actuator module to adjust the platform resistance, restoring the force feedback of real ski slopes, effectively solving the difficulty of center-of-gravity control for beginners, and enhancing the authenticity and user experience of sliding simulation. This configuration has been widely applied in implemented products such as the Joyful World Double-Plank Ski Simulator System.

1.1.3 Environmental and posture auxiliary sensors

In practice, the system is equipped with an SHT30 temperature and humidity sensor and a TFmini Plus laser ranging sensor to form a collaborative monitoring system. The SHT30 temperature and humidity sensor collects real-time environmental temperature and humidity data, providing references for low-temperature scene simulation and equipment environmental adaptability adjustment, thereby avoiding the limitations of single temperature monitoring. The TFmini Plus laser ranging sensor assists in monitoring the relative position between the skier and the equipment, preventing safety hazards caused by excessive movement amplitude, while also optimizing the accuracy of scene interaction to achieve a synchronous effect of "the scene follows the user's movement," enhancing the continuity of the immersive experience and ensuring equipment safety, thus adapting to the needs of multi-user scenarios.

1.1.4 Main controller

The STM32F103VET6 chip is selected as the main controller. Verified through practice, this chip balances performance with research, development, and maintenance costs, and it can efficiently undertake key tasks such as data acquisition and processing, algorithm computation, peripheral communication, and decision output. It adopts a Cortex-M3 core with an operating frequency of up to 72 MHz, enabling it to efficiently handle complex tasks including multi-sensor data fusion and posture analysis, thereby ensuring the coordinated and efficient operation of all system modules. It integrates 512 KB of flash memory and 64 KB of SRAM, meeting the requirements for program code storage, data caching, and intermediate result storage. It is equipped with various communication interfaces such as SPI, I2C, and UART, facilitating data transmission with various sensors, drive modules, display devices, and communication modules, thus adapting to the needs of multi-device collaborative operation and reducing subsequent maintenance difficulty.

1.1.5 Actuator drive module

The module adopts a collaborative working mode of a hydraulic drive unit and a motor drive unit. Through practical debugging and optimization of parameter configuration, it can accurately achieve posture adjustment and resistance control of the simulated sliding platform. The hydraulic drive unit uses a small electric hydraulic push rod combined with a hydraulic damping component, enabling a stepless slope adjustment of 0-35 degrees and bump simulation, thus accurately restoring the terrain characteristics of different ski trails such as alpine, cross-country, and flat slopes. The motor drive unit uses a 28BYJ-48 stepper motor, which controls the motor speed and direction through PWM (pulse width modulation) signals and drives the transmission mechanism to adjust the sliding resistance of the simulation platform, matching the resistance in real time according to the skier's movements and speed, thereby restoring the friction feedback between the skis and the snow surface. The drive module works in conjunction with the pressure sensing and posture sensing modules, dynamically adjusting the platform posture and resistance to meet the needs of skiers at different skill levels. Verified through practice, this module operates stably and can meet the requirements of long-term continuous use[3].

1.1.6 Power supply, communication, and display modules

The power supply module uses a 26650 lithium-ion battery pack. Through practical optimization of the combination method, it forms a 12V battery pack with a total capacity of 5000mAh, which can meet more than 8 hours of continuous operation on a single charge, making it suitable for long-duration usage scenarios such as professional training and commercial operations. The module is equipped with a charging protection module and a voltage stabilization module to prevent overcharging, over-discharging, and overcurrent, ensuring stable power supply and reducing the impact of low-temperature environments on battery performance.

1.2 Software practice implementation

The software system is built upon the hardware practice configuration and optimized for implementation using existing mature algorithms. Through multi-scenario practice debugging, it has formed stable and efficient functional modules that balance training scientificity with immersive experience. All software functions have been validated through practice, meeting the application needs of different scenarios while supporting subsequent functional upgrades and optimizations.

1.2.1 Posture analysis and feedback algorithm

As the core technology for the practical application of ski simulators, this algorithm has been trained and optimized with a large amount of practical data. It can accurately process the posture and pressure data collected by multiple sensors, and perform motion recognition, deviation analysis, and personalized feedback[4].

1.2.2 Scene rendering and terrain simulation algorithm

The Unreal Engine 4 is used for scene modeling and rendering. Through practice, the scene database and rendering parameters have been optimized to build a scene system that includes various terrains such as alpine, cross-country, and flat slopes, as well as various weather conditions including sunny, snowy, and foggy weather. It supports 2K high-definition image output and is equipped with light and shadow rendering technology to enhance scene realism and restore the visual experience of outdoor ski trails.

1.2.3 Personalized training planning algorithm

Based on the practical needs of different user groups, the algorithm optimizes its adaptability. It can generate customized training programs according to the user's skiing level and training needs, adapting to different scenarios such as beginner introduction, intermediate improvement, and advanced fine training.

1.2.4 Motion control and human-computer interaction module

The motion control module, after repeated practical debugging, can accurately receive the decision-making commands from the main controller and control the operation of the actuator drive module, achieving posture adjustment, resistance control, and safety protection of the simulation platform. Through the encoder, it provides real-time feedback on the motor speed and platform posture, and adjusts the output in combination with the PID algorithm to ensure control accuracy and improve the stability and reliability of sliding simulation. Verified through practice, the response time for platform posture adjustment is $\leqslant 0.5$ seconds, allowing it to quickly adapt to the user's motion changes.

2. Practical application scenarios and effects of the ski simulator

Based on current implementation cases of ski simulators, they have been widely used in various scenarios such as physical education, professional training, fitness and entertainment, and community promotion. In combination with the application needs of different scenarios, differentiated application models have been formed. Verified through practice, these models can effectively address the core pain points in each scenario, improve application efficiency and user experience, and contribute to the popularization and development of ice and snow sports. Among these, the Joyful World Double-Plank Ski Simulator System has been successfully applied in diverse settings such as schools, enterprises and institutions, gyms, and homes, demonstrating good practical effects.

2.1 Practical application in physical education scenarios

Physical education is one of the most widely used scenarios for ski simulators, mainly covering winter sports courses in primary and secondary schools and universities, training in ice and snow sports specialty schools, and instruction in professional ice and snow training institutions. With the optimization of equipment configuration and functions based on teaching needs, a standardized teaching application model has been formed, and the practical effects are significant.

2.2 Practical application in professional training and competition preparation scenarios

The ski simulator has been gradually applied to the training of professional ski teams and competition preparation, becoming an important auxiliary piece of equipment for professional training. With its accuracy and functions optimized according to the needs of professional training, the simulator can simulate the terrain and snow conditions of different competition venues, helping athletes systematically and meticulously refine their movements and improve preparation efficiency. In practice, professional ski teams use the simulator's precise motion capture and scene simulation functions to restore the snow trail characteristics of various competition venues, allowing athletes to maintain training conditions even in the off-season. By recording athletes' training data and analyzing their movement weaknesses, the simulator provides data support for coaches to develop targeted preparation plans, helping athletes optimize their movements and improve competitive performance. At the same time, the simulator can simulate complex snow conditions and unexpected scenarios, enhancing athletes' emergency response capabilities. Verified through practice, simulator-assisted training can effectively improve athletes' movement stability and competitive level, providing strong support for competition preparation. In addition, the simulator can also analyze, in real time, the trajectory and turning angles of athletes when crossing gates during giant slalom events, helping athletes optimize their racing movements and adapt to the needs of competition preparation.

2.3 Practical application in fitness and entertainment scenarios

The fitness and entertainment scenario is the core scenario for the market-oriented application of ski simulators, mainly covering fitness venues, indoor ice and snow experience halls, and commercial leisure areas. In combination with the public's entertainment and fitness needs, the equipment experience and functions have been optimized, forming diversified entertainment application models with high market acceptance[5].

2.4 Practical application in community and public promotion scenarios

As the efforts to bring ice and snow sports into communities intensify, the ski simulator gradually enters communities, becoming an important vehicle for popularizing ice and snow sports among the public. In combination with the needs of community residents, it optimizes the operational difficulty and usage cost of the equipment, providing residents with low-cost, low-risk skiing experiences and popularizing the culture of ice and snow sports.

3. Problems and optimization strategies in the practical application of ski simulators

3.1 Main problems existing in practical application

Based on the current implementation experience of ski simulators, although their application scenarios are continuously expanding and practical effects are significant, some problems still exist in the process of large-scale application, affecting application quality and promotion speed. These problems mainly focus on three aspects.

First, the equipment cost is relatively high, making promotion difficult. At present, the hardware configuration and software development costs of ski simulators are relatively high, leading to high equipment prices. For primary and secondary schools, communities, and small fitness venues, the procurement cost pressure is significant, making large-scale introduction difficult. At the same time, the subsequent operation and maintenance costs of the equipment are high, requiring professional personnel for maintenance and debugging, which further increases application costs and limits its popularization.

Second, technical adaptability needs to be improved. Some ski simulators that have been implemented still have deficiencies in scene simulation authenticity and motion capture accuracy. For example, the terrain simulation of complex ski trails is not precise enough, and there is a delay in motion capture during high-speed sliding, affecting user experience. At the same time, the functional adaptability of some simulators is insufficient, making it difficult to meet the personalized needs of users of different ages and skill levels, such as the lack of dedicated functions for the elderly and children.

Third, the application mode is relatively single. In most scenarios, the application of ski simulators is still dominated by simple experience and training, lacking diversified application modes. For example, the integration with ice and snow sports events, science popularization, and parent-child activities is not close enough, making it difficult to fully realize its application value. At the same time, there is a lack of sharing of application experience between different scenarios, which hinders further improvement of the simulator's application effect.

3.2 Targeted optimization strategies

Based on the problems existing in practical application and in combination with the current level of technological development and implementation experience, the following optimization strategies are proposed to facilitate the large-scale practical application and technological upgrading of ski simulators[6].

First, cost control should be optimized to lower the threshold for promotion. In terms of hardware configuration, the procurement cost of core hardware can be reduced through bulk purchasing and technological optimization. At the same time, miniaturized, low-cost simulator models should be developed to meet the procurement needs of scenarios such as primary and secondary schools and communities. In terms of software, the research and development process should be optimized and mature algorithms should be reused to reduce development costs. In addition, a standardized operation and maintenance system should be established, and training for operation and maintenance personnel should be provided to reduce subsequent maintenance costs and promote the popularization of simulators.

Second, technical adaptability should be improved to optimize user experience. The posture capture algorithm and scene rendering algorithm should be continuously optimized to enhance motion capture accuracy and scene simulation authenticity, reduce latency during high-speed sliding, and further restore the sliding experience of real ski trails. In consideration of the needs of users of different ages and skill levels, equipment functions should be optimized and dedicated modes should be developed, such as a simple mode for children and a leisure mode for the elderly, to improve functional adaptability. At the same time, the equipment operation interface should be optimized to enhance ease of use, allowing different groups to quickly get started. By leveraging the interactive advantages of the Joyful World Double-Plank Ski Simulator System, the gameplay and user experience of the equipment should be further enriched.

Third, application modes should be innovated to expand application value. Deep integration of ski simulators with diverse scenarios should be promoted, and application modes should be innovated. For example, simulator racing competitions can be organized in conjunction with ice and snow sports events. In combination with science popularization, activities for promoting knowledge of ice and snow sports and simulator experiences can be carried out. In combination with parent-child activities, parent-child interactive modes can be developed to enhance the application value of simulators. At the same time, a mechanism for sharing application experience across different scenarios should be established, excellent practical cases should be summarized, and the overall application effect of simulators should be improved, thereby contributing to the goal of "engaging 300 million people in ice and snow sports."

4. Conclusion

The practice and application of ski simulators have effectively broken through many limitations of outdoor skiing, making them an important vehicle for the popularization of ice and snow sports, the improvement of professional training, and public entertainment and fitness. Based on existing implementation cases and technical experience, their hardware configuration and software functions have gradually matured, forming diversified application scenarios and standardized application models, demonstrating significant practical effects in fields such as physical education, professional training, fitness and entertainment, and community promotion. For example, the Joyful World Double-Plank Ski Simulator System has been successfully implemented in multiple scenarios, providing a reference example for practical application in the industry.

At present, ski simulators still face problems such as high cost, insufficient technical adaptability, and single application modes in practical application, which restrict their large-scale promotion and the improvement of application quality. In the future, it is necessary to continuously optimize technology and cost control, improve equipment adaptability and user experience, innovate application modes, promote deep integration of simulators with diverse scenarios, and expand application value. At the same time, the sharing of application experience across different scenarios should be strengthened to promote technological iteration and large-scale application of ski simulators, thereby contributing to the nationwide popularization and high-quality development of ice and snow sports, and providing new ideas and references for the practical application of intelligent sports equipment.

Fund Projects

Supported by the General Project of the Key Research and Development Program of the Shaanxi Provincial Department of Science and Technology (2024SF-YBXM-680), the Youth Innovation Team Project of the Shaanxi Provincial Department of Education (22JP070), and the 2025 College Student Innovation and Entrepreneurship Project: Snow Leap Pro --- "Dynamic Analyzer of Intelligent Ski Wearable Devices".

References

[1] Lu Laibing, Li Jin, Yang Shaoxiong. Application Status of Robots in the Sports Field. Journal of Hebei Institute of Physical Education, 2022, 36(6).
[2] Zhang Lei, Wang Hao, Li Na. Design and Implementation of an Immersive Ski Training Simulator. Techniques of Automation and Applications, 2023, 42(5).
[3] Han Xixi, Zhang Lei, Wang Junqi, et al. Design and Implementation of a Wireless Charging Intelligent Robotic Vacuum Cleaner System. Mechanical Engineering and Automation, 2024(2).
[4] Zhi Guanghua. Linear Control Method of the Ball Trajectory of a Tennis Training Robot. Machinery Design & Manufacture, 2024(10).
[5] Fan Li, Yang Hong. Obstacle Avoidance Control System for Sports Motion Path Based on Improved PRM Algorithm. Information Technology, 2024(4).
[6] Liu Yang, Chen Jing. Design of a Multi-Sensor Fusion Ski Posture Monitoring System. Sensor Technology and Application, 2023, 11(3).
[7] Wang Yu, Li Li. Application Research of Immersive Virtual Reality Technology in Ice and Snow Sports Training. Sports Science and Technology Bulletin, 2024, 32(2).
[8] Chen Ming, Li Juan. Design of an Intelligent Sports Equipment Control System Based on STM32. Application of Electronic Technology, 2023, 49(8).
[9] Zhao Yang, Zhang Min. Advances in the Application of Virtual Reality Technology in Sports Training. China Sport Science, 2024, 44(3).
[10] Joyful World (Beijing) Sports Technology Co., Ltd. Double-Plank Ski Simulator System, 2026-01-12.