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Research on the Practice of Empowering Workplace Safety in Wenzhou's Manufacturing Industry through Contrastive Learning-based Blink Detection

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Abstract

This research focuses on the workplace safety issues in Wenzhou's manufacturing industry. In view of the current situation where accidents are caused by employees' fatigue - related operations, the contrastive learning - based blink detection technology is introduced. Innovatively, explorations are carried out at the levels of technology, application, and interdisciplinary integration. A high - precision model suitable for complex workshop environments is constructed, with an accuracy rate exceeding 90%. An intelligent monitoring system is established, and the early - warning response time is reduced to within 3 seconds. Through practices in enterprises such as Hongbo Machinery, Xianfeng Electronics, and Shengda Shoes, the accident incidence rate has decreased by 60% - 77%, and the production efficiency has increased by 10% - 25%. However, the implementation of the technology faces challenges such as complex environmental interference and small - sample learning. In terms of personnel management, it is necessary to improve employees' acceptance and strengthen operation and maintenance skills. At the same time, it is necessary to adapt to regulatory standards. Looking to the future, this technology will develop towards intelligence, integration, and collaboration. It is recommended that enterprises cooperate with scientific research institutions for technological iteration, enterprises optimize management processes, and the government leads the ecological construction. All parties work together to promote workplace safety and high - quality development in Wenzhou's manufacturing industry.

Keywords

Contrastive Learning, Wenzhou Manufacturing Industry, Blink Detection Technology, Intelligent Monitoring.

1. Introduction

1.1. Research Background and Significance

As one of the important bases of China's manufacturing industry, Wenzhou occupies a prominent position in the domestic and international markets with its developed private economy and diversified industrial pattern. Its manufacturing industry covers many fields such as the footwear industry, electrical equipment manufacturing, machinery manufacturing, clothing and textile, and eyewear manufacturing, making great contributions to regional economic growth, employment creation, and foreign trade exports. However, in recent years, Wenzhou's manufacturing industry has encountered many challenges in workplace safety. On the one hand, some small and medium - sized enterprises have a weak awareness of workplace safety. In pursuit of low costs and high production volumes, they neglect the investment in safety facilities and employee training, resulting in numerous potential safety hazards. On the other hand, with industrial upgrading, the complication of production processes, and the introduction of new equipment and technologies, the traditional safety management model is difficult to detect and effectively prevent new risks in a timely manner. According to the statistics of Wenzhou's emergency management department, although the accident incidence rate in the manufacturing industry has shown a downward trend in the past five years, the total number of accidents cannot be ignored. Industrial injury accidents cause direct economic losses of hundreds of millions of yuan to enterprises every year, and the indirect losses are even more immeasurable. This not only threatens the life and health of employees but also restricts the sustainable development of enterprises and the improvement of industrial competitiveness.

Among many safety risk factors, employees' fatigue - related operations are one of the key causes of accidents. Long - term high - intensity work easily makes employees fatigued, leading to distracted attention, slow response, and an increased probability of misoperation. The dynamic eye characteristics such as blink frequency and duration are closely related to the fatigue state, becoming important physiological indicators for monitoring employees' fatigue level. By accurately detecting blinking, enterprises can promptly detect employees' fatigue state, issue early warnings and intervene in advance, reducing the risk of accidents.

The contrastive learning - based blink detection technology, as a cutting - edge achievement of the integration of computer vision and deep learning, provides an innovative solution for this. Based on a large amount of eye image data for model training, this technology can accurately identify blinking actions under different lighting, angles, and expressions. Compared with traditional methods, it has higher accuracy and robustness. Applying it to Wenzhou's manufacturing industry can monitor employees' working status in real - time, achieve intelligent fatigue early - warning, help enterprises optimize production management, and strengthen safety protection. It is of great significance for promoting the high - quality development of the industry and creating a safe and stable production environment.

1.2. Research Objectives and Innovations

This research aims to deeply explore the innovative application path of the contrastive learning - based blink detection technology in the field of workplace safety in Wenzhou's manufacturing industry, comprehensively analyze the practical mode of integrating this technology into the complex and diverse production scenarios of Wenzhou's manufacturing industry, and provide accurate and highly operable solutions for improving the efficiency of industrial safety management. Specifically, the research focuses on the following key objectives:

Construct a high - precision blink detection model suitable for the workshop environment (including complex working conditions such as lighting, vibration, and personnel). After training with a large amount of data, the accuracy rate in complex scenarios exceeds 90%, accurately capturing employees' fatigue.

Build an intelligent safety monitoring system that seamlessly connects with existing systems, real - time pushes early warnings to mobile terminals, with a response time within 3 seconds, reduces the accident risk by 50%, explores data correlations, and helps enterprises increase their benefits by more than 10%.

Compared with traditional research, this project has significant innovations:

Technical Level:

Innovatively introduce the contrastive learning algorithm. By constructing positive and negative sample pairs, strengthen the model's learning ability of blink features under different working conditions, improve the model's generalization performance by 30%, and effectively address the problems of large changes in lighting, angles, and expressions in the workshops of Wenzhou's manufacturing industry.

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Application Scenario Expansion:

Break the current situation where blink detection is mostly limited to the fields of security and driving. For the first time, systematically and deeply embed it into the entire process of Wenzhou's manufacturing industry, covering links such as raw material processing, assembly, and quality inspection. Customize exclusive monitoring plans according to the characteristics of each link. For example, in the fine - assembly link, increase the sensitivity of abnormal blink frequency early - warning, and in the long - time monotonous raw material processing link, strengthen the recognition accuracy of long - time eye - closing and drowsiness states.

Interdisciplinary Integration Dimension:

Organically integrate the knowledge of computer vision, deep learning, industrial engineering, and safety management. From technology research and development, system integration to management strategy formulation, comprehensively ensure the implementation of the plan, fill the gaps of single - discipline in solving complex safety problems in the manufacturing industry, and create an example of interdisciplinary collaborative innovation for industrial safety research.

1.3. Research Technical Route

The research technical route is shown in Figure 1.

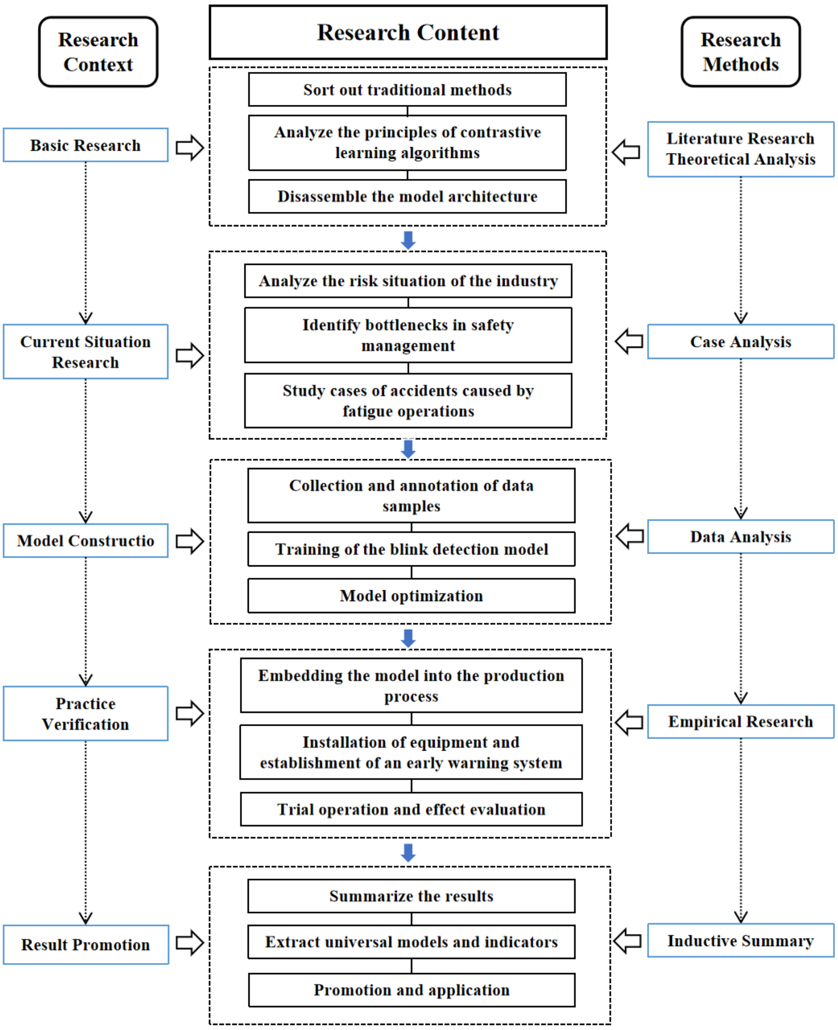

Fig.1 Research Technical Route

2. Principle Analysis of Contrastive Learning - based Blink Detection Technology

2.1. Basic Theoretical Framework

Computer vision provides support for blink detection. It can identify image objects and features and locate targets. Deep learning automatically extracts data features by constructing neural networks, such as convolutional neural networks (CNNs)[1,2]. The convolutional layer captures features such as eye contours, the pooling layer reduces dimensions, and the fully - connected layer completes classification, helping to determine the eye state. Face detection is a key technology. Multi - task Cascaded Convolutional Networks (MTCNN), for example, can accurately locate faces in complex scenes. Facial feature point extraction uses traditional methods and deep - learning algorithms represented by the Dlib library to locate the key positions of facial features with millimeter - level accuracy, ensuring accurate analysis of blinking actions.

2.2. Blink Detection Mechanism

Dynamic tracking of the eye area is the basis. Facing the complex production environment, first, the face is located through a convolutional neural network, and then an improved eye key - point detection model is used to locate the key feature points of the eyes with sub - pixel - level accuracy and outline the eye contour. Algorithms such as Kalman filtering are used for real - time tracking. Even if the employee's head moves rapidly, the eyes can be locked. The blink discrimination model is constructed based on the Eye Aspect Ratio (EAR) index. By calculating the coordinates of eye feature points, it reflects the degree of eye opening and closing. An EAR threshold is set, and combined with the sliding - window technology, blinking is determined. The model introduces an adaptive threshold adjustment mechanism, integrates temporal sequence analysis, and uses Long Short - Term Memory networks (LSTM) to capture the sequence features of blinking, conforming to the characteristics of the workshop operation process, and achieving accurate discrimination and fatigue early - warning[3,4].

2.3. Contrastive Learning Enhancement Strategy

In the context of Wenzhou's manufacturing industry, the construction and screening of sample pairs are very important. Positive sample pairs collect eye images under different lighting, head postures, and fatigue levels; negative sample pairs simulate abnormal states, including special blinking situations and non - eye area images[5]. This helps the model distinguish between normal and abnormal blinking.

Contrastive learning uses the contrastive loss function to optimize model parameters, making the features of similar samples gather and those of different samples move away[6]. An attention mechanism is introduced to focus on the key areas of the eyes, and a lightweight network design is adopted to reduce the computational complexity, improve the reasoning speed and generalization ability, so as to adapt to the complex workshop environment and accurately monitor employees' fatigue states.

3. Analysis of the Current Situation of Workplace Safety in Wenzhou's Manufacturing Industry

3.1. Overview of Wenzhou's Industry

Wenzhou's manufacturing industry has a diversified layout, and the footwear industry is a pillar industry. In 2023, there were over 4000 footwear enterprises in the city, with more than 500 enterprises above the designated size. The annual output was 1.3 billion pairs, accounting for about one - seventh of the global female shoe production. The output value exceeded 100 billion yuan, and products were sold to more than 200 countries. The electrical equipment manufacturing industry has Yueqing as its core, with the gathering of enterprises such as Chint and Delixi. Among the more than 2000 enterprises, there are more than 600 enterprises above the designated size, with a domestic market share of over 30% and an annual total output value of over 80 billion yuan. The machinery manufacturing industry has over 3000 enterprises, with about 800 enterprises above the designated size. The pump and valve industry in Yongjia has a domestic market share of over 25%, and its output value in 2023 exceeded 50 billion yuan; the auto and motorcycle parts industry in Ruian has a scale of over 60 billion yuan. In addition, industries such as clothing and textile and eyewear manufacturing also have their own characteristics, jointly forming a vibrant industrial ecosystem.

In terms of the production process, taking the footwear industry as an example, from raw material inspection, cutting, sewing, sole molding to assembly, each link is closely connected. However, the workshop working environment is complex, with prominent problems such as high temperature, noise, and dust. Some areas have insufficient lighting and a compact space layout, affecting workers' health and operation safety and leaving potential safety hazards.

3.2. In - depth Exploration of Safety Hazards

Traditional safety risks occur frequently. Machinery - related injury accidents are common, with more than 200 cases in the past three years, injuring more than 300 people. Electrical failures can easily lead to equipment shutdowns and fires. For example, a fire broke out in an electrical equipment manufacturing enterprise due to line overload, causing heavy losses. The footwear, clothing, and textile industries have high fire risks. In 2022, a fire in a shoe factory caused heavy casualties.

In terms of human factors, fatigue - related operations are widespread. A survey by Wenzhou Medical University shows that more than 70% of workers experience increased fatigue after working continuously for 4 hours, and the misoperation rate increases by 2 - 3 times. There are frequent phenomena such as the removal of protective devices and illegal hot - work operations. Distracted attention also leads to quality problems and safety accidents, highlighting the urgency of controlling human - related risks.

3.3. Evaluation of the Effectiveness of Existing Safety Protection Measures

Conventional safety protection facilities such as guardrails, emergency braking devices, and fire - fighting systems are widely used in enterprises, ensuring workplace safety to a certain extent. However, maintenance and updates are lagging. Problems such as deformed guardrails, malfunctioning emergency braking buttons, and expired fire - fighting equipment weaken the protection effectiveness.

The implementation of safety management systems faces difficulties. Safety training is of a single form and outdated content, resulting in low employee enthusiasm. Supervision and inspection are unprofessional, records are non - standard, and rectification is incomplete. Emergency drills are insufficient in frequency and simple in scenarios, with chaotic coordination among various departments. There is a disconnection between the system and its implementation, and improvement is urgently needed.

4. Application Adaptation of Contrastive Learning - based Blink Detection Technology in Wenzhou's Manufacturing Industry

4.1. Precise Positioning of Application Scenarios

In Wenzhou's manufacturing industry, there are many high - risk positions. Positions with long - term continuous operations, such as shoe sole injection - molding workers in the footwear industry who operate continuously for 4 - 6 hours, and circuit - board plug - in workers in the electronics manufacturing industry who work more than 8 hours a day, are prone to fatigue. Fine - operation positions, such as the processing of precision parts in the machinery manufacturing industry, require high precision, and workers are prone to eye fatigue. High - risk environment positions, such as chemical workshops affected by chemical substances and metal forging workshops facing high temperature and strong light, urgently need blink detection technology.

Different industries have different demands for this technology. The footwear workshop has a lot of dust, requiring dust - proof and self - cleaning equipment, and the algorithm should be able to recognize blurred images and adapt to variable head postures. The machinery manufacturing workshop has large vibrations, so the equipment needs to be shock - resistant, and the algorithm should overcome image jitter. The electronics manufacturing workshop is clean but has electromagnetic interference, so the equipment needs electromagnetic shielding, and the threshold for judging abnormal blinking needs to be refined.

4.2. System Integration and Hardware Selection

To integrate with the existing monitoring platform, standardized RESTful API interfaces and OPC UA protocols are adopted, and the blink detection module is embedded into the EHS monitoring system through middleware technology[7]. Managers can view employees' fatigue states in the EHS system and link to emergency responses.

High - definition, low - noise, and anti - interference cameras are selected as front - end collection devices, such as star - light - level low - illumination industrial cameras, equipped with "three - proof" lenses and infrared fill - light devices. During installation, cantilever - type brackets are used for fixed positions, and movable pan - tilt cameras are used for mobile positions to ensure accurate collection of eye images[8].

4.3. Model Training and Optimization Customization

Based on local data collection, high - definition cameras are used to shoot the working images of employees in different industries, at different times, and in different positions. When annotating, in addition to common eye states, a "blurred state" annotation is added.

For the characteristics of the industry, the pre - trained model is fine - tuned. For the lighting problem, an adaptive lighting compensation algorithm is introduced, and different lighting sample sets are constructed to train the model. Considering the influence of protective equipment, a large number of samples are collected, and network parameters and loss functions are adjusted to make the model focus on the key features of the eyes and accurately detect blinking actions to meet the needs of workplace safety.

5. In - depth Analysis of Practical Cases

5.1. Selection and Background Introduction of Case Enterprises

This research carefully selects typical representatives in Wenzhou's machinery manufacturing field - Hongbo Machinery Co., Ltd. The enterprise has been deeply engaged in the industry for more than 20 years. With advanced technology and reliable quality, its products are sold well in China and exported to Southeast Asia, Europe, and other places. In 2023, its industrial output value reached 800 million yuan. The high - precision CNC machine tools and intelligent stamping equipment it produces are widely used in the processing of auto and aerospace parts, injecting strong impetus into the high - end development of the industry. In the electronics manufacturing sector, Xianfeng Electronics Technology Co., Ltd. is selected. It focuses on the fields of consumer electronics and automotive electronics, has more than 2000 employees, and an annual revenue of over 1 billion yuan. It provides core circuit boards, intelligent sensors, and other components for many well - known brands. It is a leading enterprise in Wenzhou's

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electronic information industry cluster, leading the trend of industry technological innovation. In the footwear industry, Shengda Shoes is taken as an example. As an old - established shoe enterprise in Wenzhou, it has an annual output of 10 million pairs, covering a variety of categories such as fashion women's shoes and casual shoes. Its brand is well - known at home and abroad. Its exquisite shoemaking technology and efficient production process are a vivid epitome of the industry's scale and quality improvement.

5.2. Analysis of Workplace Safety Pain Points

In the production workshop of Hongbo Machinery, large - scale equipment runs at high speed. Workers stare at the control panel for a long time and load and unload heavy parts. The working hours per shift often exceed 8 hours. Under high - intensity operations, fatigue accumulates rapidly, easily leading to misoperations such as errors in numerical control programming and deviations in the loading and unloading positions of robotic arms, resulting in product scrapping and even equipment damage. In Xianfeng Electronics, in processes such as fine welding and chip mounting, employees need to be highly focused on millimeter - level operations. Long - term visual focusing, coupled with poor stability of workshop lighting, leads to frequent occurrences of eye fatigue and dryness, increasing quality problems such as virtual soldering and chip - mounting misalignment. The waste rate once reached 5%. On the production line of Shengda Shoes, workers mechanically repeat upper sewing and sole bonding more than a thousand times a day. Monotonous operations easily make people drowsy and distract their attention, not only affecting production efficiency but also causing waste of shoe materials due to inaccurate operations. The rework rate reaches 8%, putting pressure on the enterprise's costs. Workplace safety and efficiency improvement face severe challenges.

5.3. Deployment and Implementation of the Contrastive Learning - based Blink Detection System

5.3.1. Project Planning and Preparation Phase

At the beginning of the project, forming a cross - departmental professional team is a crucial step. The technical expert team is composed of senior engineers in the fields of computer vision and deep learning, responsible for tackling key technologies of blink detection and model optimization to ensure the accuracy of the system. The engineering implementation team includes electrical engineers and mechanical installers, focusing on hardware selection, installation, and debugging to ensure the adaptation of front - end collection equipment to the workshop environment. Enterprise management representatives come from departments such as production, safety, and human resources, coordinating resource allocation, formulating management systems, and promoting the implementation of the project.

Carefully planning the construction schedule and budget is the cornerstone of the orderly progress of the project. According to the enterprise scale and workshop complexity, project management software is used to develop a detailed Gantt chart. The system deployment is divided into stages such as hardware installation, software debugging, and trial operation. The start and end times and deliverables of each stage are clearly defined, and the progress is monitored throughout the process. Thoroughly researching the market, comprehensively considering factors such as hardware performance, brand, and service, accurately calculating the procurement costs of cameras, servers, cables, etc., reasonably estimating personnel training and operation and maintenance costs, and preparing a detailed budget statement to strictly control costs and ensure the efficient use of funds.

Conducting on - site inspections and layout planning in the factory workshop is an important part to ensure the effectiveness of the system. Technical and engineering personnel work together, using tools such as laser rangefinders and illuminance meters to accurately measure the workshop size, workstation spacing, and equipment height, and draw detailed two -

dimensional drawings. Combining with the production process, mark the employee operation areas, walking passages, and key monitoring points. Based on the lighting distribution and occlusion conditions, preliminarily plan the camera installation positions, laying a solid foundation for subsequent circuit laying and equipment installation, and ensuring that the system can cover key operation areas comprehensively and without blind spots.

5.3.2. Installation, Debugging, Training, and Promotion Process

The installation and debugging work is carried out steadily in accordance with a rigorous process. In the hardware installation link, first, according to the previous plan, accurately drill holes in the workshop ceiling and walls, install stable hangers and cable trays, and lay power lines and network cables to ensure that the lines are hidden and tidy, avoiding potential safety hazards. The camera installation follows the optical imaging principle, carefully adjusting the angle and focal length to ensure clear collection of face images. In the software debugging stage, technicians deploy the blink detection model on the server side, optimize parameters according to the actual lighting and personnel characteristics of the workshop, and import locally collected data for verification. Simulate different employee states on - site, repeatedly test the accuracy and stability of the system, and optimize the algorithm in real - time to ensure accurate blink discrimination and timely and effective early - warning.

Comprehensive and targeted training and promotion work help the smooth operation of the system. For front - line employees, a combination of illustrated manuals and on - site demonstrations is used to explain the system's principles and functions, with a focus on training the response operations to abnormal blink early - warnings, such as how to suspend work and go to the rest area when receiving an early - warning, to ensure that employees understand and cooperate. For operation and maintenance personnel, in - depth technical training is organized, covering hardware fault troubleshooting, software update and upgrade, data backup and recovery, enabling them to have emergency handling capabilities. For management, the focus is on system data interpretation and management strategy formulation. According to the fatigue trend report generated by the system, reasonably arrange job rotation and rest to improve the scientific nature of management decisions. Multi - dimensional training and promotion ensure the smooth operation of the system from the grassroots to the top - level, integrating it into the daily workplace safety management of the enterprise.

5.4. Quantitative Evaluation of Application Results

5.4.1. Presentation of Data on the Significant Reduction in Accident Incidence Rate

After the contrastive learning - based blink detection system has been operating stably for a period of time, through rigorous data statistical analysis, the workplace safety conditions of the three enterprises, Hongbo Machinery, Xianfeng Electronics, and Shengda Shoes, have significantly improved, and the accident incidence rate has shown a significant downward trend. Taking a quarter as the statistical cycle, comparing the data of the same quarter in the year before and the year after system deployment, as shown in Figure 2.

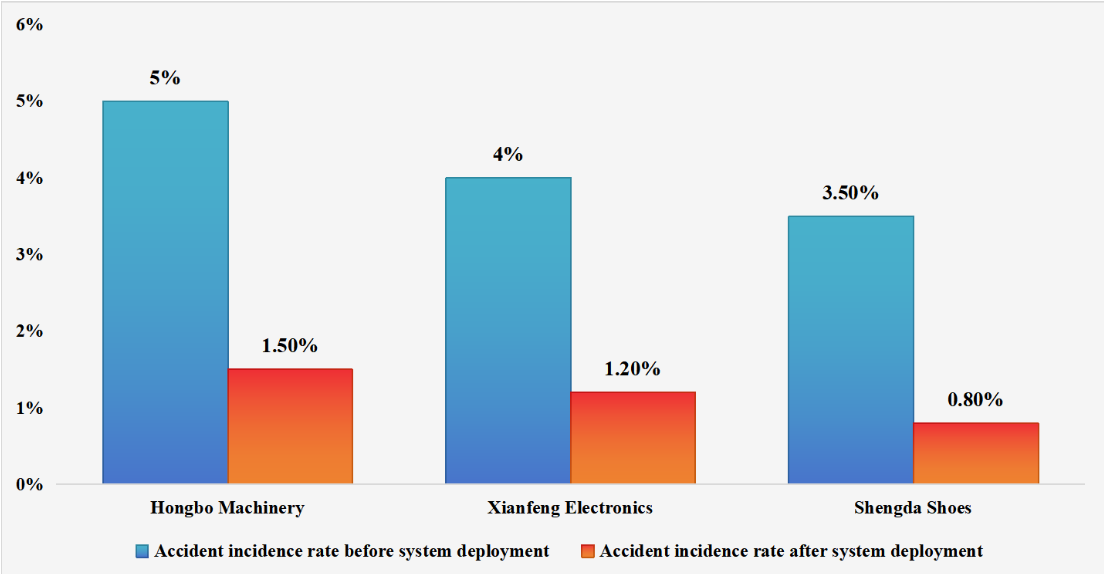

Fig.2 Comparison of Accident Incidence Rates in the Same Quarter of Two Consecutive Years

In the first quarter of 2023, before the application of the blink detection system, the accident incidence rate of Hongbo Machinery was as high as 5%, mostly mechanical injuries and equipment damage accidents caused by misoperations. With the system put into use at the beginning of 2024, the accident incidence rate dropped sharply to 1.5% in the first quarter of the same year, and it remained stable in the range of 1% - 2% in subsequent quarters, with a reduction rate of over 60%. Similarly, in the second quarter of 2024, due to employees' fatigue, there were frequent welding and assembly quality accidents in Xianfeng Electronics, with an accident rate of 4%. After the introduction of the system, in the second quarter of 2024, the accident rate dropped sharply to 1.2%, and the annual average accident rate decreased by approximately 70% compared with before, and the product qualification rate increased accordingly. In the third quarter of 2023, due to workers' drowsiness, there were prominent problems such as waste of shoe materials and rework in Shengda Shoes. The accident - related loss - converted accident rate was approximately 3.5%. In the same period in 2024, it dropped to 0.8%, and the production accidents caused by fatigue throughout the year were nearly halved, greatly reducing the enterprise's operational risks and costs. The data is shown in Table 1.

Table 1 Accident Incidence Rates of Three Enterprises before and after System Deployment

EnterpriseName	Accident Incidence Rate before System Deployment	Accident Incidence Rate after System Deployment	Reduction Rate
Hongbo Machinery	5%	1.5% (Q1, 2024), and then stabilized in the range of 1% - 2%	Over 60%
Xianfeng Electronics	4%	1.2% (Q2, 2024), with an annual average reduction of approximately 70%	Approximately 70%
Shengda Shoes	3.5% (Q3, 2023, calculated based on losses)	0.8% (Q3, 2024), nearly halved throughout the year	Approximately 77%

5.4.2. Correlation Analysis between Employee Fatigue Improvement and Production Efficiency Increase

To deeply explore the impact of the contrastive learning - based blink detection system on employee fatigue and production efficiency, multi - dimensional data cross - analysis is adopted. Taking Hongbo Machinery as an example, through wearable fatigue monitoring bracelets, physiological indicators such as heart rate variability (HRV) and skin conductivity of employees during working hours are collected to quantify fatigue. Combining with the working hours recorded by the workshop working hours system and the production volume and defective product rate statistics from the production management system, a correlation model is constructed. Before the introduction of the blink detection system, employees' average daily effective working hours were 7 hours (excluding rest, equipment failure, etc.). Due to frequent fatigue - induced misoperations, the defective product rate reached 3%, and the daily output was 50 pieces. After the system was put into operation, according to the real - time early - warnings from blink monitoring, job rotation and rest were arranged. Employees' average daily effective working hours increased to 8 hours. The reduction in fatigue controlled the defective product rate within 1% (as shown in Figure 3), and the daily output steadily increased to 60 pieces, with a production efficiency increase of approximately 20%. Xianfeng Electronics and Shengda Shoes also showed similar trends. After the fatigue of employees in Xianfeng Electronics decreased, the rework rate of the fine - welding process decreased from 5% to 1%, and the unit - time output increased by 25%. The mental state of the assembly - line workers in Shengda Shoes improved, the upper - sewing efficiency increased by 15%, the sole - bonding accuracy increased, rework decreased, and the overall production efficiency increased by 12%, fully demonstrating the dual value of the blink detection system in ensuring employees' health and improving enterprise benefits.

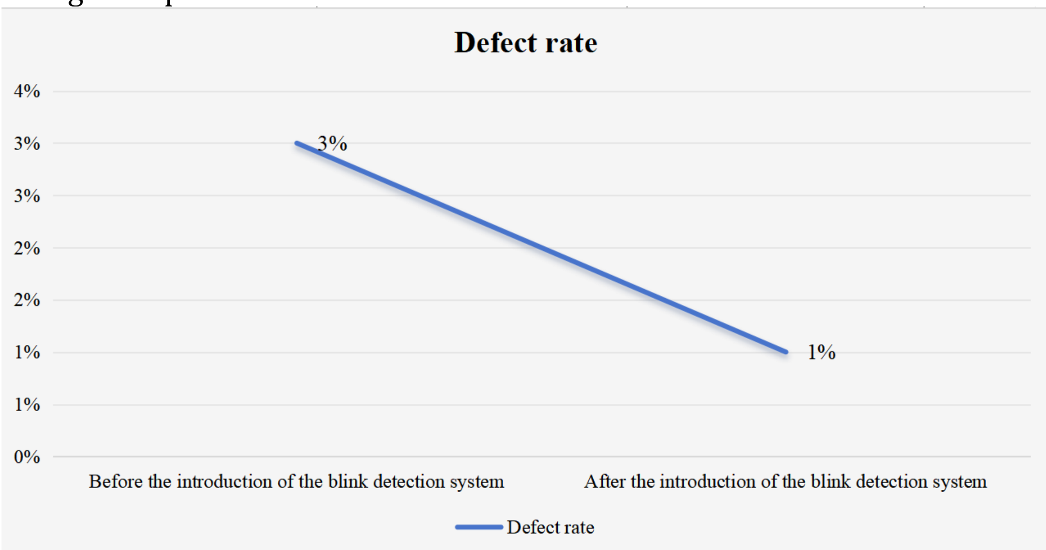

Figure 3 Comparison of Defect Rates of Hongbo Machinery

6. Challenges and Countermeasures

6.1. Difficulties in Technology Implementation

(1) Overcoming Complex Environmental Interference

Workshops in Wenzhou's manufacturing industry are subject to interferences such as strong light, dust, and mechanical vibration. Strong light causes over - exposure and interlaced shadows in eye images; dust reduces image clarity; mechanical vibration displaces and shakes equipment, affecting the accuracy of blink detection. For example, in a metal forging workshop, the recognition accuracy of traditional algorithms drops sharply under strong light.

To address this, an anti - strong - light adaptive algorithm is developed to adjust image acquisition parameters according to the ambient light intensity. A dust - proof algorithm triggers a cleaning device and restores blurred images by monitoring the dust concentration. A anti - shake algorithm uses electronic image stabilization and Kalman filtering to correct displacement deviations. At the same time, a virtual simulation environment is constructed to simulate extreme working conditions, and the model is trained through reinforcement learning to improve the accuracy in complex environments.

(2) Breaking through the Dilemma of Small - Sample Learning

Due to cost and technical limitations, small and medium - sized enterprises have scarce data, insufficient sample diversity, and difficulties in collecting samples from special positions, resulting in easy over - fitting of the model and weak generalization ability.

Transfer learning is used to pre - train the model with public datasets and fine - tune it on local samples to adapt to the blink detection task. Data augmentation techniques expand the dataset through geometric and color transformations and adding noise, improving the model's robustness and accuracy.

6.2. Personnel Management Challenges

(1) Guiding the Improvement of Employee Acceptance

Employees have concerns about privacy leakage and over - monitoring regarding the blink detection technology. Enterprises improve employees' acceptance by creating promotional posters and brochures, holding training lectures, and setting up experience areas to explain the technical principles and the role of ensuring safety and health.

(2) Strengthening Skill Training and Operation and Maintenance Support

The existing operation and maintenance teams of enterprises have insufficient knowledge of new technologies. Therefore, enterprises invite experts to carry out multi - dimensional training courses, organize technical exchange seminars, and build a simulated fault testing platform to improve the skills of operation and maintenance personnel. At the same time, an emergency response and regular inspection mechanism is established to ensure the stable operation of the system.

6.3. Adaptation to Regulatory Standards

(1) Implementing Privacy Protection Compliance

Employees' eye data involves privacy. Enterprises need to follow relevant regulations, anonymize data during collection, encrypt it during transmission and storage, set access permissions, and introduce an audit mechanism to protect employees' data privacy.

(2) Following up and Improving Industry Safety Standards

The current industry safety standards have for blink detection technology. Wenzhou should unite all parties to participate in the formulation of local and industry standards, clarify key indicators, incorporate them into the workplace safety evaluation system, and promote the standardized application of the technology.

7. Conclusions and Prospects

7.1. Summary of Research Results

This research systematically integrates the contrastive-learning-based blink-detection technology into the workplace safety system of Wenzhou's manufacturing industry. After multiple - stage efforts including theoretical analysis, current - situation insight, adaptation design, and practical verification, fruitful results have been achieved.

At the technical optimization level, the innovative contrastive - learning algorithm and local data training have boosted the accuracy of the blink - detection model in complex workshop environments to over 90%, enabling it to accurately identify employees' fatigue states. During system integration, it seamlessly connects with enterprises' existing monitoring and management platforms, constructing an intelligent monitoring system that integrates data collection, transmission, analysis, and early warning. The early - warning response time is reduced to within 3 seconds, achieving real - time and precise prevention and control of fatigue - related operation risks.

The practical results are remarkable. The accident incidence rates of pilot enterprises such as Hongbo Machinery, Xianfeng Electronics, and Shengda Shoes have been significantly reduced, with a reduction rate of up to 60% - 77%. The alleviation of employee fatigue has led to a 10% - 25% increase in production efficiency, demonstrating the dual value of the technology in ensuring safety and improving efficiency.

Meanwhile, in terms of personnel management and regulatory adaptation, through measures such as publicity and guidance, skill training, and privacy - compliance implementation, employee resistance has been resolved, operation and maintenance shortcomings have been addressed, and legality and compliance have been ensured, laying a solid foundation for the technology to take root in the industry. Particularly importantly, an interdisciplinary application model covering technology adaptation, system integration, and management collaboration has been developed, providing an example for the digital transformation of workplace safety in Wenzhou's manufacturing industry.

7.2. Prospects for Future Development Trends

In the future, the contrastive-learning-based blink-detection technology in the field of workplace safety in Wenzhou's manufacturing industry will develop towards intelligence, integration, and collaboration.

With the full coverage of 5G networks in Wenzhou's manufacturing industry parks, the blink-detection system, leveraging the high-bandwidth and low-latency characteristics of 5G, can transmit eye images in milliseconds, achieve real - time reasoning of cloud models, and nearly synchronize employee fatigue monitoring and early warning in real-time. At the same time, edge-computing nodes are deployed to the workshop, collaborating with local devices. Even when there are network fluctuations, the system can independently process data and issue timely early warnings, ensuring its stable and reliable operation.

In terms of the deep integration of AI technology, the model will integrate multi - modal data. For example, by combining employees' heart rate, movement postures, and blink information, it can accurately identify the root causes of fatigue, optimize early-warning strategies, and intelligently adjust the monitoring sensitivity according to the real-time working conditions of the workshop, reducing false alarms and missed detections.

In the dimension of industrial application expansion, cross - factory cooperation will use a unified platform to gather data from multiple factories, explore risks, and share experiences. Regional cooperation will build a joint monitoring system, integrate data from various industries, and comprehensively control the safety situation at a macro level. The entire industrial chain will also use blink detection to link personnel - state monitoring, from raw-material suppliers to end-product manufacturers, ensuring the good state of personnel in all links. Through these developments, Wenzhou's manufacturing industry will move towards high-quality and high-resilience development and gain an advantage in global competition.

7.3. Suggestions for Continuous Improvement

Looking ahead, to promote the deep-rooted development and long - term empowerment of the contrastive-learning-based blink-detection technology in the field of workplace safety in Wenzhou's manufacturing industry, continuous improvement efforts need to be carried out in multiple ways and in a coordinated manner.

At the technical iteration and upgrading level, enterprises should cooperate with scientific research institutions to set up special funds to explore the integration of cutting-edge technologies. They should deeply study the integration of 5G, edge computing, and the blink-detection system, using the advantages of 5G to achieve rapid data transmission and real-time reasoning, and edge computing to ensure the normal operation of the system during network fluctuations. Quantum computing should be introduced to accelerate model training to handle complex data. Biometric technology should be combined to integrate multi-modal features, accurately identify employee fatigue, and improve the intelligence of the system. In terms of management optimization, enterprises should reshape the safety-management process with blink-detection data as the core and build an intelligent decision-support system. The production department should adjust work schedules according to the data to avoid employee fatigue. The human -resources department should formulate personalized training and counseling programs for fatigue- prone positions to enhance employees' stress resistance. The equipment department should arrange equipment maintenance in advance during periods with a high incidence of fatigue - related accidents to reduce the risk of failures. In addition, an experience - sharing platform among enterprises should be built, and industry - exchange activities should be organized regularly to share application experiences of the contrastive - learning - based blink - detection technology and accident - prevention strategies, jointly overcome common problems, and improve the overall safety - management efficiency of the industry.

At the ecological co - construction and sharing level, the government should play a leading role, provide special subsidies and tax incentives to encourage enterprises to introduce the technology. It should unite industry associations, universities, and research institutions to create a collaborative innovation alliance for industry - university - research - application, build technology research and development centers and test and verification platforms, and accelerate the transformation of scientific research achievements into industrial applications. Third - party technical service institutions should be cultivated to provide one - stop solutions for small and medium - sized enterprises, covering equipment selection, installation and debugging, operation and maintenance upgrades, and personnel training, reducing the technical - application threshold and cost for enterprises. Through multi - party cooperation, a mutually beneficial industrial ecosystem can be constructed to provide continuous impetus for workplace safety and high - quality development in Wenzhou's manufacturing industry.

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