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REPORT

Innovative Applications and Future Development of Intelligent Diagnostic Devices in Traditional Chinese Medicine: An AI Review

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ABSTRACT

This paper reviews the current applications, challenges, and future development trends of intelligent diagnostic devices in Traditional Chinese Medicine (TCM). With continuous advancements in artificial intelligence (AI), machine learning (ML), and data analytics, intelligent diagnostic devices are gradually being integrated into TCM diagnostics, covering various aspects such as pulse diagnosis, tongue diagnosis, and facial diagnosis. These advanced technologies not only enhance the objectivity and accuracy of TCM diagnosis but also suggest promising trends for personalized treatment development. This paper examines recent progress in intelligent devices for tongue image analysis, pulse diagnosis, and facial image analysis, highlighting existing challenges related to data quality, interdisciplinary collaboration, and ethical issues. Furthermore, the paper envisions future trends in intelligent diagnostic devices, emphasizing the importance of miniaturization, portability, telemedicine, and standardization. We expect intelligent technology to accelerate the modernization and globalization of TCM. Finally, the paper calls for future research to focus on the deep integration of TCM and modern technology, promoting the standardization of intelligent diagnostic devices and improving diagnostic reliability to foster innovative developments in TCM diagnostics.

KEYWORDS

intelligent diagnostic devices, traditional Chinese medicine (TCM), artificial intelligence (AI), machine learning (ML), tongue diagnosis, pulse diagnosis, facial diagnosis, data analysis, personalized treatment, modernization transition

1 INTRODUCTION

The core of Traditional Chinese Medicine (TCM) diagnosis lies in the four diagnostic methods—inspection, listening and smelling, inquiry, and palpation-emphasizing syndrome differentiation and treatment tailored to everyone and blending an integrated approach with individual differences. However, with the rapid advancement of modern technology, intelligent devices have gradually been

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introduced into TCM diagnostics, bringing new vitality to the objectivity and accuracy of these methods. Intelligent technologies such as artificial intelligence (AI), sensor technology, and data analysis have been applied to devices such as pulse diagnostic instruments, tongue diagnosis analyzers, and facial diagnostic image analysis tools, promoting the modernization and digitalization of TCM diagnostic techniques.

In recent years, research has increasingly focused on both the applications and challenges of AI in TCM diagnostics. For example, AI applications in TCM have been the focus of increasing research. A review highlighted AI's potential in diagnostics, treatment, and personalized medicine while suggesting future development directions [1]. Another study explored AI-based diagnostic methods using tongue image analysis, showing benefits for improving diagnostic accuracy [2]. Research has also examined AI's role in intelligent diagnostic systems for pulse, tongue, and facial diagnosis, emphasizing the modernization of TCM diagnostic technologies [3]. Challenges in AI-based TCM diagnostics, such as data quality and interdisciplinary collaboration, have been discussed, along with proposed directions for modernization [4]. AI's role in personalized TCM treatment and its clinical translation effects have also been evaluated [5]. A systematic examination of AI in TCM diagnostics proposed a new model integrating AI with TCM theory, offering a framework for future development [6]. More work has investigated AI's potential and challenges in tongue, pulse diagnosis, and personalized treatment [7]. These studies offer valuable insights into AI applications in Traditional Chinese Medicine.

The applications of AI in TCM are extensive, showing enormous potential in areas such as tongue image analysis, the four diagnostic methods, and personalized treatment. By using data analysis and machine learning (ML), AI can improve accuracy and efficiency in diagnostics, treatment, and prognostic assessment. Specifically, AI applications in tongue image recognition, pulse data analysis, and personalized treatment plans significantly reduce human error, providing fanatical support for the scientific modernization of TCM. However, AI in TCM also faces numerous challenges, including data quality, complexities in interdisciplinary collaboration, and issues with quantifying and computationally interpreting TCM theories. Literature suggests that setting up standardized databases and promoting a deeper integration of TCM with AI will be essential to advancing TCM diagnostic practices and improving patient care quality.

This paper aims to review the current applications of intelligent diagnostic devices in TCM, discussing the advantages and limitations of these technologies, analyzing current technical challenges, and exploring the potential and trends for future developments in TCM diagnostic equipment. Specifically, by reviewing relevant literature, this paper reveals the innovative applications of AI in TCM and its potential to transform diagnostic practices. First, traditional TCM diagnostic methods are summarized, followed by an introduction to the application of modern intelligent diagnostic devices in TCM, including their roles and limitations in data collection and analysis. Next, key challenges in device applications are discussed, concluding with an analysis of future trends and a summary of current research findings, aiming to provide references and guidance for AI applications in the field of Traditional Chinese Medicine.

2 OVERVIEW OF TRADITIONAL CHINESE MEDICINE DIAGNOSTIC METHODS

2.1 The four diagnostic methods in TCM

In TCM, the four diagnostic methods form the core diagnostic framework, enabling a comprehensive assessment of a patient's overall health [8–10]. This framework includes four main aspects:

i) Observation (Wàngzhěn): This method assesses a patient's internal health through external signs, such as tongue appearance, complexion, mental state, and behavior. The tongue, including its coating, color, and shape, is particularly significant in reflecting organ function and is a unique hallmark in TCM diagnostics.
ii) Listening and Smelling (Wénzhěn): This involves analyzing vocal sounds, breathing, and any distinctive body odors. For example, abnormal breathing patterns or halitosis can show underlying health issues.
iii) Inquiry (Wènzhěn): By questioning the patient about their medical history, symptoms, daily habits, and diet, practitioners gather essential information to find the disease's nature and etiology.
iv) Palpation (Qièzhěn): Focused on pulse diagnosis, this technique evaluates pulse rhythm, strength, and depth to assess qi and blood circulation, organ functions, and potential pathological changes.

2.2 Limitations of TCM diagnostics

While TCM's four diagnostic methods offer a structured diagnostic framework, they also have certain inherent limitations [11, 12]:

i) Subjectivity: TCM diagnostics depend on the practitioner's experience and knowledge, leading to potential variations in diagnosis for the same patient among different practitioners, resulting in a lack of consistency in diagnostic outcomes.
ii) Challenges in Data Standardization: Most diagnostic data in TCM is not quantified, making it challenging to set up unified standards. For instance, evaluations of complexion or pulse characteristics are difficult to digitize, limiting scientific research and hindering TCM's integration into contemporary data-driven medical frameworks.
iii) Environmental Influence: The accuracy of TCM diagnosis can be affected by external environmental variables, including emotional state, temperature, and humidity. These factors may cause fluctuations in the patient's physiological state, thereby affecting diagnostic precision.

2.3 The necessity of integrating modern technology

With advancements in information technology, the development of AI, sensor systems, and big data analytics has progressively enhanced the objectivity, consistency, and effectiveness of TCM diagnostics [1–7]. Modern technology enables real-time collection of pulse wave data and tongue images, using big data analysis to standardize diagnostic procedures. This integration has started a new era of quantification and objectivity in TCM. For example:

i) Sensor Technology: High-precision sensors used in pulse diagnosis can quantify pulse waveforms, providing more precise pulse analysis.
ii) Machine Learning: ML processes and analyzes tongue images, finding potential health patterns, which enhances the objectivity and accuracy of tongue diagnosis.

The integration of modern technology not only addresses the limitations of traditional TCM diagnostics but also provides a pathway for the digitalization, standardization, and personalization of TCM treatment.

3 APPLICATION OF INTELLIGENT DIAGNOSTIC DEVICES IN TCM DIAGNOSTICS

Intelligent diagnostic devices merge the practices of TCM with modern scientific technology, primarily through the application of AI. This integration leverages AI's capabilities in data analysis and ML to enhance diagnostic accuracy, treatment efficacy, and prognosis. However, successfully implementing AI in TCM diagnostics presents challenges, including data quality, interdisciplinary collaboration, and medical ethics. Addressing these challenges is crucial for fully realizing AI's potential in TCM practice and improving patient care.

3.1 Current status of AI in TCM

The application of AI in TCM is progressively advancing, especially in the fields of diagnostics and treatment, showing significant potential for development. In recent years, AI technologies, such as ML and image analysis, have been used to improve TCM diagnostic methods.

Based on a review of relevant literature, Table 1 provides a summary of the application of various intelligent diagnostic devices in pulse diagnosis, tongue diagnosis, facial diagnosis, and the four diagnostic methods of TCM. This table highlights the technical features, advantages, and challenges associated with each device. Below, we discuss the main research progress and challenges related to each type of intelligent diagnostic device.

Table 1. Applications, features, advantages, and challenges of intelligent diagnostic devices in TCM diagnostics

Device Type	Application Area	Technical Features	Advantages	Challenges
Pulse Diagnostic Devices	Pulse Diagnosis	– Advanced control systems (RBF neural network, NARX model) – Portable design (Raspberry Pi platform) – Pressure and photoplethysmographic (PPG) sensors, pulse wave analysis	– Improves diagnostic precision and consistency – Allows real-time data collection and processing	– Requires further optimization of signal accuracy and consistency – Challenges with noise and variability in signal processing
Tongue Diagnostic Devices	Tongue Image Analysis	– Deep learning, computer vision – Image segmentation techniques (Yolo-V5, U-Net model) – Convolutional neural network (CNN)	– Provides standardized, objective, and reproducible support – Enhances diagnostic accuracy and prognosis	– Lack of high-quality, standardized datasets – Requires further integration of TCM and AI technologies
Facial Diagnostic Devices	Facial Expression Analysis and Vital Sign Monitoring	– Image recognition, facial expression analysis (CNN, LSTM model) – Wearable devices check temperature, pulse, respiration, etc.	– Increases objectivity and precision in diagnosis – Real-time monitoring enables prompt intervention	– Privacy and data security concerns – Limited ability to fully capture the complexity of TCM diagnosis
Integrated Four Diagnostic Methods (IAOIP)	Observation, Listening/ Smelling, Inquiry, Palpation	– Machine learning applied to Four Diagnostics (IAOIP) – Data collection and preprocessing, model selection	– Provides objective data to reduce subjectivity – Improves automated diagnostic systems	– Insufficient coverage by automated systems – AI models require improved adaptability and accuracy

This table outlines the integration of intelligent diagnostic devices in TCM, showing how each technology supports the traditional diagnostic approach while presenting unique technical, data, and integration challenges.

Pulse Diagnostic Devices

1. Overview of Modern Pulse Diagnostic Devices: Modern pulse diagnostic devices integrate advanced technology to enhance clinical diagnosis, addressing the subjectivity and lack of standardization inherent in traditional pulse diagnosis. By incorporating advanced control systems, portable designs, and AI technology, these devices have significantly improved diagnostic accuracy and consistency.
2. Advanced Control Systems: Modern bionic pulse diagnostic systems use advanced control methodologies such as radial basis function (RBF) neural networks and nonlinear autoregressive networks (NARX) models. These systems offer high-precision control over applied pressure and increased resistance to interference. Compared to traditional proportional-integral-derivative (PID) controllers, they prove faster response times and reduced error rates, thereby enhancing diagnostic accuracy. Studies have shown that these sophisticated control mechanisms outperform traditional systems in both laboratory and clinical settings, providing reliable data for medical analysis [13].
3. Portable Pulse Diagnostic Devices: Innovations in portability have introduced pulse diagnostic devices based on the Raspberry Pi platform. These lightweight, efficient systems are capable of real-time pulse signal acquisition and algorithmic processing. Unlike conventional devices that primarily measure basic parameters, these advanced devices perform comprehensive pulse waveform analysis, making them valuable for clinical applications and remote diagnostics. For example, recent research highlights their capability to analyze pulse patterns with precision, even in dynamic environments [14].
4. Integration of Pressure and Photoplethysmographic (PPG) Sensors with Pulse Wave Analysis: Modern pulse diagnostic devices incorporate pressure sensors, PPG sensors, and pulse wave analysis techniques to provide goal, quantifiable data for TCM diagnosis. Pressure sensors, such as thin-film resistors, measure pulse depth and strength, which are critical parameters for pulse diagnosis. PPG sensors enhance accuracy by detecting light absorption changes due to blood volume fluctuations, offering precise readings for pulse frequency and rhythm [15]. Recent advancements have combined these sensors with robust algorithms to improve diagnostic reliability significantly [14].
5. Advanced Pressure-Sensing Technology: New pressure-sensing designs feature innovations such as airbags and multi-sensor arrays. These enable uniform pressure distribution across the measurement area, reducing artifacts and improving the overall accuracy of pulse diagnostic data. For instance, experimental studies prove that such designs provide a 20% increase in data consistency compared to older models [16].
6. Pulse Wave Analysis: Pulse wave analysis in modern devices employs wavelet transforms and convolutional neural networks (CNNs) to filter noise and classify pulse signals. These methods have proven instrumental in enhancing diagnostic accuracy. For example, the ResNet18-F model achieved an 82% training accuracy rate in diagnosing diabetes, highlighting the potential of AI-driven pulse diagnosis. Incorporating such advanced analytical frameworks enables healthcare professionals to derive detailed insights from pulse data, supporting both traditional and modern diagnostic paradigms [17].

These technological integrations enable a quantitative approach to TCM diagnosis, allowing cross-validation with clinical subjective assessments. Results show a high diagnostic consistency with a Kappa statistic of 0.82 [18]. Portable platforms such as the Raspberry Pi support real-time transmission and processing, increasing

both the efficiency and accessibility of pulse diagnosis [14]. Although significant advancements have been made, further research to improve signal precision and consistency in pulse acquisition and processing, addressing challenges such as signal noise and variability to enhance the reliability of pulse diagnostic devices in modern Traditional Chinese Medicine.

Tongue Diagnostic Devices. Modern tongue diagnostic devices use deep learning, computer vision, and AI to enhance accuracy and efficiency in tongue diagnosis, providing standardized, objective, and reproducible support for TCM [19]. These systems run on both mobile and fixed devices, suitable for clinical and remote medical applications mentation technology, using the Yolo-V5 object detection module and an enhanced U-Net model, has improved segmentation accuracy by 8%–10% [19] on non-standard datasets in diverse environments. Convolutional neural networks (CNNs) such as ResNet34 effectively classify tongue characteristics, improving recognition rates for features such as tooth marks by over 10%, while visual question-answering technology further enhances health assessment accuracy [20].

To optimize systems on devices with limited computing power, lightweight deep convolutional network structures ensure efficiency and handle pixel constraints and lighting variations in mobile photography, helping digital tongue diagnosis [21]. Neural networks prove performance in tongue localization and feature recognition, supporting future development of intelligent tongue diagnosis [22]. Recent research in 2024 [23] showed that AI-driven analysis, combined with ML and complex pattern recognition technologies, can find TCM syndromes more accurately, improving diagnostic and prognostic outcomes and enhancing treatment efficacy.

Despite advancements, challenges are still, such as standardized datasets and issues with data quality. Close collaboration between AI technologists and TCM practitioners is crucial to further integrate AI into TCM for robust, evidence-based applications.

Facial and Physiological Monitoring Devices. Artificial intelligence technology has driven noteworthy progress in TCM diagnostics, particularly in enhancing diagnostic accuracy and enabling prompt interventions. In facial diagnosis, image recognition and facial expression analysis through AI can help assess sub-health conditions and pathological changes, aiding TCM practitioners in more accurately evaluating health. AI systems can also integrate real-time data from wearable devices, improving diagnosis in areas such as pulse and tongue examination by enhancing objectivity and precision.

For facial expression recognition, CNN and long short-term memory (LSTM) models are widely applied to evaluate physical and mental health, with research showing a 99.89% accuracy rate in finding facial features associated with health risks [24]. Wearable devices continuously watch vital signs such as pulse, and respiration, providing real-time data for a comprehensive assessment of patient health, thereby supporting more precise and prompt interventions in TCM [25].

Artificial intelligence platforms such as ChatGPT also show promise in offering personalization and health advice, integrating closely with TCM practices to provide instant feedback, reduce diagnostic time, and improve patient satisfaction [26]. However, as AI applications in TCM expand, issues like privacy and data security are increasingly significant. Strict privacy measures are essential to protect patient information, ensuring trust and acceptance of AI technology in TCM diagnostics [27].

Supporting the inspection, auscultation/olfaction, inquiry, palpation (IAOIP) diagnostic approach. Recent research in 2024 [28] explored ML applications in the four diagnostic methods of TCM. Since TCM diagnosis traditionally relies heavily on subjective judgment, ML offers objective data support, reducing diagnostic subjectivity. Key steps in achieving this goal include data collection, preprocessing, model

selection, and evaluation metrics. Although progress is notable, further optimization of automated systems is needed to ensure comprehensive diagnostics.

Limitations, Personalized Treatment, and Development of Intelligent Medical Tools. The future of intelligent medical tools in TCM is promising but faces challenges, including data consistency, environmental factors, and high device costs, which limit their use in small clinics [29]. However, AI-driven personalized treatment tools such as massage robots and acupuncture systems have proved potential. Through data analysis and ML, these tools can create individualized treatment plans based on patient characteristics, improving treatment precision and clinical outcomes. Such tools not only enhance treatment efficacy but also show potential for symptom relief and functional improvement such as in asthma treatment, where symptom improvement and lung function have been significantly enhanced [30].

Nevertheless, AI applications in TCM treatment must address challenges related to data privacy, regulatory frameworks, and fairness and linguistic differences should also be considered to ensure accessibility and equity in medical services [31]. Research in 2024 [32] noted that massage robots and acupuncture systems provide new directions for personalized treatments and could improve efficacy by merging TCM with modern technology, enhancing diagnostic precision.

4 THE ROLE OF ARTIFICIAL INTELLIGENCE AND DATA ANALYTICS IN TCM DIAGNOSTICS

The role of AI and data analytics in TCM diagnostics primarily focuses on enhancing diagnostic accuracy, standardizing data collection, and implementing personalized treatment plans. The integration of AI and data analytics is transforming TCM significantly, especially in processing complex diagnostic data (such as pulse and tongue analyses) through ML algorithms. This advancement not only eases the digital transition of TCM but also addresses the subjectivity challenges often present in traditional diagnostics. Below is an analysis of the advancements in relevant technologies:

i) Data Collection and Integration: The development and application of intelligent diagnostic devices enable the collection and integration of crucial TCM diagnostic data, such as tongue images, pulse images, and pulse readings, to create comprehensive health records for each patient [19]. These devices not only help standardize data collection but also promote the sharing and further analysis of diagnostic information, supporting TCM's digital transformation [33].
ii) Application of AI and ML Algorithms: AI and ML algorithms play a leading role in analyzing and classifying data from TCM diagnostics, such as pulse and tongue images, to extract effective diagnostic models [34]. These technologies digitize the complex differential diagnosis process, reduce human error, and improve both diagnostic efficiency and accuracy.
iii) Personalized Diagnosis: Personalized diagnosis is another significant application of AI in TCM. By analyzing individual patient data, AI systems can create tailored health plans based on this information. This approach is especially valuable in managing chronic diseases, where ongoing monitoring and personalized treatment recommendations help improve long-term patient outcomes [34].

Despite the promising potential of AI in TCM, challenges are still present, including data consistency issues, the complexity of devices, and the impact of environmental factors on data accuracy [18]. Ensuring data quality and device reliability

is essential for successfully integrating AI into TCM diagnostics. Although advances in AI are promising, addressing data quality and ethical issues is still crucial. Close collaboration between AI technologists and TCM practitioners is key to unlocking AI's full potential to enhance TCM practices and improve patient care [34].

Table 2 provides an overview of the applications of AI in TCM diagnostics, detailing the main technical advantages, challenges faced, and potential solutions to these challenges.

Table 2. Roles, challenges, and issues of AI and data analytics in TCM diagnosis

Application Area	Description	Challenges and Issues
Data Collection and Integration	Intelligent diagnostic devices are used to collect and integrate key data such as tongue images and pulse readings, creating comprehensive health records that advance the digitization of TCM diagnostics.	Issues with data consistency, device complexity, and the impact of environmental factors on data accuracy.
Artificial Intelligence and Machine Learning	AI and ML algorithms are applied to analyze and classify TCM diagnostic data, aiding in the extraction of effective diagnostic models, reducing human error, and improving diagnostic efficiency and accuracy.	Diagnostic models need to be improved to accurately process and classify complex TCM data.
Personalized Diagnosis	Through analyzing individual patient data, AI customizes health plans, especially for chronic disease management, providing continuous monitoring and personalized treatment recommendations to improve long-term patient outcomes.	Implementing personalized diagnosis requires high-quality patient data, and the accuracy of data collection and analysis is critical.
Digital Transformation	AI drives the digital transformation of TCM by standardizing data collection and improving diagnostic processes, enabling more efficient and correct diagnoses.	Data quality and device reliability remain key challenges for the successful integration of AI with TCM.
Collaboration between Technologists and TCM Practitioners	Collaboration between technology experts and TCM practitioners is essential to advance AI applications in TCM diagnostics, addressing issues related to data quality and ethics.	Cross-disciplinary collaboration is needed to ensure the clinical effectiveness and ethical compliance of the technology.

This table outlines the main application areas of AI and data analytics in TCM diagnostics, along with the challenges met in promoting digital diagnostics, enhancing personalized treatments, and ensuring data and device quality. Cross-disciplinary collaboration is vital for the dependable and ethically compliant integration of AI into TCM practices.

5 FUTURE TRENDS AND CHALLENGES IN INTELLIGENT DIAGNOSTIC DEVICES FOR TRADITIONAL CHINESE MEDICINE

As advanced technologies such as AI, the Internet of Things (IoT), and big data continue to develop, they are driving profound transformations in intelligent diagnostic devices for TCM. Key future trends and challenges in the development of TCM diagnostic devices are outlined as follows:

5.1 Technological advancements

i) Multidisciplinary Integration and Innovation: The integration of multiple disciplines will be a core trend in TCM diagnostic device development. Combining AI, IoT, and big data will significantly enhance diagnostic efficiency and perfect data collection and analysis. For instance, wearable devices using IoT can collect and send patient health data in real-time, providing comprehensive support for

TCM diagnosis. This fusion enables more precise personalized treatment plans, advancing the digital and standardized transformation of TCM practices.

ii) Portability and Accessibility: With technological progress, TCM diagnostic devices are likely to become more compact and portable, especially in wearable technology. These devices can watch patients' health around the clock, providing instant diagnostic feedback, which improves the accessibility and convenience of TCM. For chronic disease patients, portable devices enable continuous monitoring and personalized treatment plans, promoting the precision and personalization of Traditional Chinese Medicine.

iii) Telemedicine and Personalized Treatment: The integration of telemedicine and intelligent diagnostic devices is a promising direction for the future. Intelligent devices can collect and analyze patient health data in real time, supporting personalized treatment. Telemedicine is particularly valuable in remote areas with limited medical resources, providing patients with convenient access to TCM care. Additionally, intelligent systems can adjust treatment plans based on patients' changing needs, ensuring personalized, prompt care, and enhancing the effectiveness of Traditional Chinese Medicine.

5.2 Key challenges

i) Data Quality and Standardization: The diversity and subjectivity of TCM diagnostic data creates challenges in setting up standardized datasets for AI applications. Diagnostic outcomes may vary according to the practitioner's experience, lacking uniform diagnostic criteria. To enhance the efficiency and reliability of AI systems, it is essential to set up standardized data input protocols and a unified diagnostic vocabulary.

ii) Interdisciplinary Collaboration and Technical Integration: The integration of AI with TCM requires close interdisciplinary collaboration to ensure AI algorithms can accurately interpret and respect TCM theories. For instance, in TCM's four diagnostic methods (observation, listening, inquiry, and pulse-taking), AI relies on precise data preprocessing and ML models. As TCM concepts such as "Qi" and "Yin-Yang" are highly abstract, collaboration between technical experts and TCM practitioners is critical.

iii) Ethics and Humanistic Considerations: The integration of AI in TCM offers significant advancements in diagnostic precision and efficiency but raises ethical concerns that must be addressed to preserve TCM's foundational humanistic values. TCM emphasizes a holistic, patient-centered approach that includes not only physical assessments but also the emotional and spiritual well-being of patients—elements difficult for AI to replicate. Over-reliance on AI risks depersonalizing care and weakening the trust inherent in the physician-patient relationship. To ensure balance, AI should serve as an auxiliary tool to complement, not replace, the ability and compassionate care of TCM practitioners. By providing detailed diagnostic data and evidence-based insights, AI can support decision-making while leaving final judgments to practitioners, ensuring a personalized and context-aware approach. Ethical principles such as patient-centered care, transparency, trust, and cultural integrity must guide AI's application, with practitioners receiving adequate training to integrate AI effectively. Interdisciplinary collaboration between AI developers and TCM experts is essential to design systems that respect TCM's holistic philosophy. This balance between innovation and tradition ensures AI enhances TCM's capabilities while upholding its ethical and humanistic principles.

iv) Herbal Medicine Research and Standardization: In herbal medicine research and prescription analysis, AI still faces challenges due to insufficient pharmacological research and data. The complexity of TCM formulations poses difficulties for AI applications, as a lack of systematic pharmacological studies limits AI's understanding of TCM mechanisms. Moreover, database quality issues affect the reliability of AI systems. Although AI can discover potential effects of TCM herbs through data mining, more high-quality databases are needed to support standardization in herbal medicine research.

v) Balancing Technology with Traditional TCM Values: The introduction of AI should carefully keep the traditional values of TCM, especially practitioners' holistic analysis abilities and humanistic care. AI should be viewed as an auxiliary tool to improve diagnostic and therapeutic outcomes, not as a replacement for traditional TCM practices. Through the collaborative development of AI and TCM knowledge, it is possible to enhance overall healthcare quality while preserving the essence of Traditional Chinese Medicine.

5.3 Prospects

The widespread adoption of intelligent diagnostic devices in TCM relies on advancing standardization and internationalization processes. Establishing unified TCM diagnostic standards and device certification systems will enhance the global acceptance and application of these technologies. As TCM diagnostic databases continue to grow, the next generation of intelligent TCM diagnostic devices will evolve toward standardization and regulation, laying a robust foundation for TCM to achieve greater recognition on the global stage.

1. Specific Examples of Future Applications
    1. Pulse Diagnostic Devices: Devices such as the TCM-Pulse AI analyzer have already proved the capability to provide detailed pulse waveform analyses. These systems integrate CNNs, and wavelet transforms to detect subtle pulse variations, such as those indicative of cardiovascular conditions. Future iterations may incorporate real-time feedback and cloud-based data sharing for comprehensive diagnostic support.
    2. Tongue Diagnostic Devices: AI-powered tongue imaging systems, such as the Tongue View analyzer, use image processing algorithms to evaluate features like tongue coating, shape, and color under standardized lighting conditions. These devices have been proven effective in diagnosing gastrointestinal disorders. Upcoming advancements aim to enhance the diagnostic range by integrating spectral analysis for more correct assessments of tongue moisture and texture.
    3. Integration of Big Data and IoT: Intelligent diagnostic devices are expected to use big data and IoT for more personalized TCM healthcare experiences. For example, IoT-enabled wearable devices could check real-time pulse signals, respiratory patterns, and other physiological data, seamlessly integrating them with existing TCM diagnostic databases to offer tailored health insights.

2. Technological and Interdisciplinary Innovations
   The next generation of intelligent TCM diagnostic devices will emphasize:
    1. Personalization: Devices will adapt to individual physiological and lifestyle variations, ensuring precise diagnostics tailored to unique patient profiles.

2. Convenience: Portable and wearable diagnostic devices will provide accessible TCM care for remote and underserved populations.
3. Standardization: Unified diagnostic protocols and certification systems will enhance global credibility.
4. Internationalization: Cross-border collaborations and harmonized standards will pave the way for TCM to gain wider recognition and application internationally.

With advancements in AI, big data, and IoT, intelligent TCM diagnostic devices will significantly improve diagnostic accuracy and treatment efficacy. By offering patients more precise and efficient healthcare experiences, these innovations will bridge traditional TCM practices with modern technological advancements, ensuring the relevance of TCM in the global healthcare landscape.

6 CONCLUSION AND RECOMMENDATIONS

The application of intelligent diagnostic devices in TCM has made significant strides, though challenges are still in areas such as standardization and diagnostic accuracy. While some devices have been adopted in clinical and research settings, limitations in technology and data analysis methods still prevent the establishment of standardized diagnostic protocols and the achievement of ideal diagnostic accuracy. Therefore, improving device performance and enhancing clinical applicability remain pressing challenges.

Future research should focus on advancing interdisciplinary integration, promoting the convergence of AI, IoT, and other modern technologies with TCM diagnostic methods. Emphasis should be placed on innovations in device miniaturization, portability, and telemedicine. By continuously integrating modern technology with traditional TCM practices, new breakthroughs and developments in TCM diagnostics can be realized. Additionally, as intelligent TCM diagnostic technologies continue to mature, setting up international standards will become increasingly crucial. This step would not only ease the global adoption and application of TCM diagnostic devices but also enhance TCM's recognition and influence worldwide.

Through sustained technological innovation and standardization efforts, it is possible to further enhance the practicality, reliability, and accessibility of intelligent diagnostic devices in TCM. This will lay a solid foundation for the modernization and internationalization of TCM diagnostic methods, paving the way for TCM to achieve a broader global presence and impact.

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