Can a holistic view facilitate the development of intelligent traditional Chinese medicine? A survey

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Can a Holistic View Facilitate the Development of Intelligent Traditional Chinese Medicine? A Survey

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Abstract—Intelligent traditional Chinese medicine (ITCM) is an emerging interdisciplinary subject. It aims to efficiently and precisely promote the prevention and treatment of diseases and health management in Chinese medicine clinical practice via the combination of traditional Chinese medicine (TCM) fundamentals and artificial intelligence technologies. Presently, it is experiencing dramatic growth in recent years. On the one hand, a holistic view, as a crucial philosophy in the theory of TCM, will be guiding the development of ITCM. On the other hand, a comprehensive discussion of the benefits of such a holistic view of ITCM is lacking. To this end, we conduct this survey by introducing the named holistic view first. Then, adaptive learning and field theory will be presented and discussed with respect to their application in ITCM. Ethical issues of ITCM will then be taken into account by human-centered TCM and potentials based on affective computing of ITCM. In addition, we give our opinions and insights on the challenges and open issues regarding the future of ITCM. We hope that this survey article can be a good guide for experts in the relevant fields.

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I. Introduction

AS one of the essences of traditional Chinese medicine (TCM), the holistic view plays a guiding role in its formation and development. Under the guidance of such a holistic view, TCM carries out syndrome differentiation and treatment (辨证论治), which features an individualized and dynamic diagnosis and treatment process based on temporal and spatial differences, highlighting the advantages of its accurate diagnosis and treatment [1]. Different from traditional medicine, modern medicine pursues linear causality and mainly understands the structure and pathophysiological changes of the human body through anatomy, experimental medicine, and more [2]. However, more and more researchers consider that the human body, as an organic whole, is not just "a stack of molecules, cells, and organs." With the rise of systems biology, bioinformatics, and other subjects, the holistic view that the human body is a complex network system has been gradually recognized by the academic community [3], [4].

First, *Huangdi Nei Jing* (黄帝内经) is the earliest existing monography of TCM theory, which comprises of two texts: *Lingshu* (灵枢) and *Suwen* (素问). According to the discussion in the *Huangdi Nei Jing*, the holistic view includes two aspects: the microwhole and the macrowhole. On the one hand, the zang-fu (脏腑) viscera of the human body are correlating with each other, the exterior and interior of our body are connected by meridians (经络), and thus, the microwhole takes shape. On the other hand, the human body, natural environment, and social environment constitute a macrowhole. In this macrowhole, human beings and the natural environment influence each other. Natural elements, such as sunlight, air, and water, affect human life activities. At the same time, human life activities are also changing the natural environment. In addition, there is a mutual dependence between people and the social environment. The political, economic, cultural, and other social factors affect human life activities, and human activities can also change the social environment.

Second, the holistic view guides the dynamic and individualized clinical syndrome differentiation and treatment of TCM [5]. As the disease changes with the physical conditions

varying according to time and space, the signs and symptoms also change correspondingly, and so are the results of syndrome differentiation and treatment.

Third, the holistic view of TCM develops from ancient materialist dialectics, such as the Yin-Yang (阴-阳) theory, the meridian theory, and the essence-qi (气) theory with the yin-yang theory at its core [6]. Yin and Yang are related as a whole and constitute all things in the world. On the one hand, Yin and Yang are mutually exclusive and complementary, which coincides with the interdependence theory of field theory. On the other hand, Yin and Yang are a unity of opposites, coexisting with each other. According to TCM, the imbalance between Yin and Yang is the root cause of diseases—that is, the balance of the human body and its balance with the natural and social environment are broken, which leads to the occurrence of diseases. Therefore, TCM attaches importance to reconciling the balance of qi and blood, and the zang-fu viscera, and curing a disease by restoring the balance of the body.

Finally, according to the understanding of meridians in *Linshu Benzang* (灵枢·本藏), the meridians are important channels carrying qi and blood, and maintaining the function of the zang-fu viscera in the human body. The meridians spread all over the body and connect the external and the internal of our body. There is an exterior–interior relationship between every two meridians and between meridians and collaterals (络). In that way, meridians and collaterals connect the zang-fu viscera and the body surface into a unified whole.

In addition, the holistic view of TCM holds that physique (形) and spirit (神) form dialectical unity. There are relevant discussions in the classic treatises of TCM, such as *Suwen Shanggu Tianzhen Lun* (素问·上古天真论), *Lingshu Benshen* (灵枢·本神), and *Suwen Yin and Yang Yingxiang Dalun* (素问·阴阳应象大论). The physique refers to our body, while the spirit means our mind. On the one hand, the physique is the material base of the spirit, and the spirit is the concrete life embodiment of the physique. On the other hand, the spirit dominates human life activities, and the body can only function well under the control of the spirit. Thus, the spirit and the physique are interdependent, actually. Mental disorders may cause physical abnormality, while physical diseases can also lead to mental disorders. At the same time, we need to notice the correlation among different emotions and between the physique and the spirit. Therefore, in the prevention and treatment of diseases, we should pay attention to the unity of physique and spirit, improve physical status through the treatment of spirit, and maintain the wholeness of the physique and the spirit [7].

Under the influence of the holistic view, TCM studies less on the objective entity and more on the subjective understanding of the patients [8]. Thus, the disease information obtained by an observer partially depends on some subjective factors. The research results are incomparable and nonrepeatable, which makes it difficult for the laws of TCM to be demonstrated and revealed [9]. However, with the gradual deepening of medical-engineering integration and the rapid development of artificial intelligence (AI), an accurate measurement of feature information has been realized, and the association mapping between feature information and disease information has been realized as well under the guidance of a holistic view. These achievements will help TCM develop a step further to become more objective and accurate.

To sum up, the holistic view is running through TCM all along: TCM sees the human body as a whole, and the diagnosis and treatment vary according to time and space [10]. Under the guidance of the holistic view, the essence of TCM is about a kind of vague reticular laws, where all feature information does not exist independently, but interdependently, which coincides with the field theory.

With the development of engineering medicine, especially AI technologies, the traditional diagnosis and treatment model gradually break down, our ability to diagnose and treat has made a step further, and intelligent medicine grows at a faster speed. Meanwhile, the prosperity of AI brings new opportunities for TCM to modernize itself, highlighting the superiority of intelligent TCM (ITCM). In the 1970s, Chinese scholars built the first expert system of TCM—the "Guan Youbo liver disease diagnosis program" [11]. Although it was only a simple logical reasoning system based on expert knowledge, as the first attempt to combine TCM and AI, it laid a solid foundation for the development of AI in the field of TCM. Today, the research on the intellectualization of TCM has experienced more than 50 years of renewal and iteration. The application of AI technology has gone deep into various aspects, such as the intelligent diagnosis of TCM, the decision-making of TCM, the health management of TCM, and the inheritance and development of TCM, and has achieved a series of remarkable results [12]. Yang et al. [13] have developed an automatic generation technology of herbal prescriptions based on tongue images that use deep learning (DL) to explore the relevance of tongue diagnosis for herbal prescriptions. By combining the two machine learning (ML) models of Bayesian networks and support vector machines, Liang et al. [14] optimized the extraction of key feature data from the traditional algorithm model in the medical records of TCM and further improved the performance of the computer-aided medical decision-making of TCM. Other scholars have built a TCM knowledge graph (TCMKG) database platform based on a knowledge map [15], providing a new way for the inheritance and development of TCM. In addition, in the present epidemic of COVID-19, the combination of TCM and AI has made an important contribution to the prevention and control of the epidemic situation. Fuzzy clustering methods, interactive optimization methods, and heuristic algorithms have been used to achieve a classification of the population and optimization of a TCM epidemic prevention scheme [16].

As an emerging interdisciplinary subject, here, we quote that the definition of ITCM in the first monograph *Generality of Intelligent Chinese Medicine: ITCM* [17] integrates AI technology, explores the essence and laws of human life and health and disease phenomena, and promotes accurate and efficient TCM clinical prevention, treatment, and health management through human–computer cooperation. ITCM seeks to standardize the complex and multidimensional four-diagnosis data
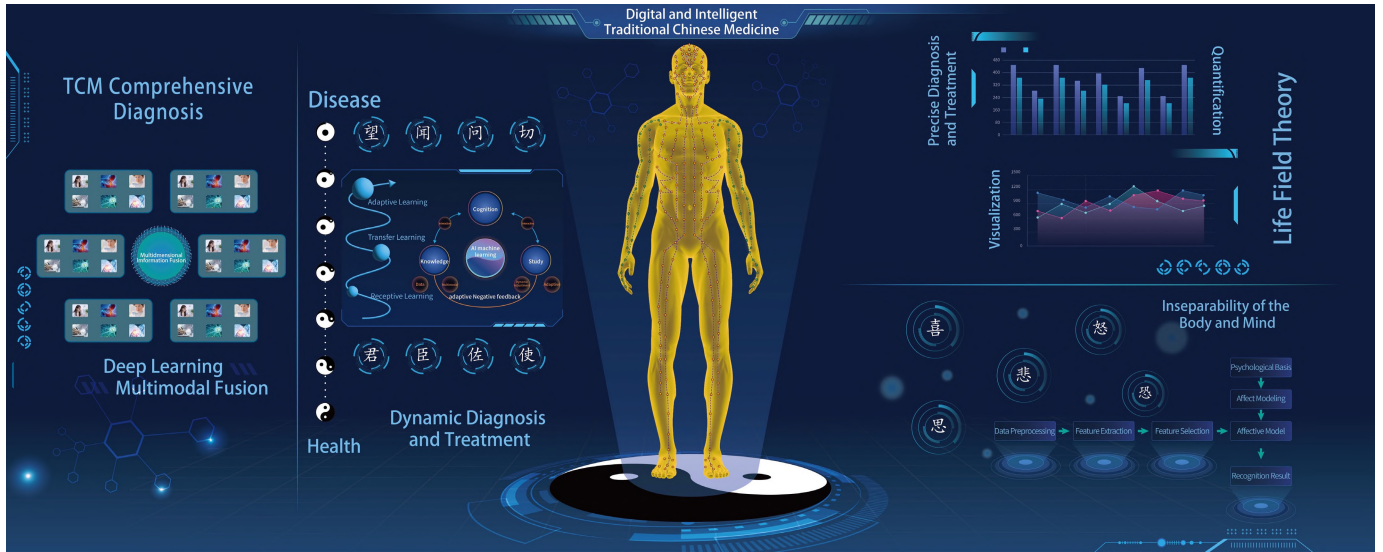
Fig. 1. Holistic view of ITCM. ITCM is an emerging interdisciplinary subject, which combines TCM fundamentals and AI technologies. The figure shows the relationship between TCM theory and AI, such as DL, adaptive learning, field theory, and affective computing under the guidance of the holistic view.

of "Inspection (望), Listening and Smelling (闻), Inquiry (问), and Palpation (切)" and integrate AI technology to build TCM diagnosis assisting models for disease prevention and treatment. Therefore, the application of AI technology in the development of TCM is inevitable. As mentioned earlier, although the application of AI technology has been widely used in the field of TCM and has achieved a series of achievements, there is still a long way to go to truly realize ITCM. It is necessary to summarize and compare the characteristics of TCM theory and AI, so as to further clarify the necessity of the combination of AI technology and TCM, and promote the intelligent development of TCM to the depth and breadth of ITCM.

As the outcome of the rapid development of modern science and technology, AI explains and quantifies information such as text, images, and voice with calculation methods mostly based on ML. There is a black box theory of formula function in the process of learning coinciding with the vague laws of TCM. Under the guidance of the holistic view of TCM, setting up knowledge-driven DL algorithms helps to transform abstract TCM theories into objective and quantifiable evidence resources. In that case, solid strides will be made in changing the blind box characteristic of simply applying a formula function in a simple DL algorithm and in realizing multimode information fusion, diagnosis, and treatment information quantification and multisource data collaborative analysis traceability.

Based on this, we will analyze the characteristics of TCM from a holistic point of view combining the microwhole with the macrowhole and try to study and explain it from the eyes of AI; Fig. 1 shows the overall architecture of the holistic view in ITCM. We will expound on the necessity and developmental conditions of the combination of TCM and AI, and point out the direction for the development of ITCM.

The main contributions of this survey article can be summarized as follows. First, we introduce the concept of a holistic view and make a comprehensive discussion on its potential power for facilitating the development of ITCM. To the best of our knowledge, this is the first time to present the holistic view methodology in the field of ITCM. Second, we study the connections between TCM holism and AI in terms of DL, adaptive learning, field theory, and affective computing. We think that both AI and TCM can receive mutual benefits by exploring the immanent advanced theories. Third, we share our perspectives and indicate future research directions in ITCM, which can be a good guide for colleagues who are interested in similar topics of ours.

The remainder of this survey article will be organized as follows. Section II will present and compare the holistic view of TCM and DL. Then, the dynamic dialectical diagnosis and treatment from TCM will be connected and compared with the adaptive learning from AI in Section III. The connections between the holistic view and field theory will be presented in Section IV. Human-centered TCM will be connected with affective computing in Section V before the challenges and open issues are given in Section VI. Finally, we conclude this survey in Section VII.

II. Holistic View in Traditional Chinese Medicine Versus a Holistic View in Deep Learning

Holism is the spiritual guidance of TCM, while DL has not developed a universal definition of a holistic view. Drawing on the experience of a holistic view from TCM, DL can enhance the interpretability of a diagnosis result and treatment performance.

A. Holistic View in Traditional Chinese Medicine

The holistic view of TCM includes two aspects. On the one hand, the human body, as an independent individual itself, is a complete microscopic whole. On the other hand, the human body and its surroundings combine to form a macroscopic whole while coexisting with each other [18]. Fig. 2 demonstrates the holism of TCM in detail.
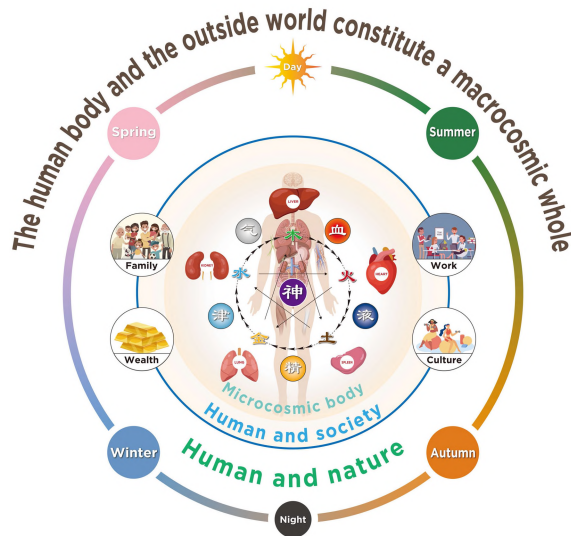
Fig. 2. Holistic view of TCM. The holistic view of TCM includes two aspects. The inner circle in the figure represents the microcosmic whole of the human body. The outer two circles in the figure represent the human body and its surroundings combined to form a macroscopic whole.

1) Holistic View on an Independent Individual Human: According to TCM, the integrity of the human body consists of three aspects, namely, the interrelation of the five zang (五脏) and six fu (六腑) viscera, the interdependence of qi and blood, and the wholeness of body and spirit [19].

First, the human body is an organic whole dominated by its heart and centered on five zang viscera. The zang-fu viscera and meridians connect with each other, and in that way, the interconnection of body structures, the coordination of bodily functions, and the interrelation of pathologies are realized. Therefore, TCM sees diseases from a holistic view and observes the overall pathological state through local changes. It holds that the variation of exterior physiological characteristics can reflect internal diseases of zang-fu viscera, which is to say "the internal conditions of the body are always reflected on the exterior of the body," as written in *Danxi Xinfa* (丹溪心法). In addition, the zang-fu viscera in the human body connect with each other pathologically; for instance, stagnation of liver qi often goes with the disfunction of the spleen transformation.

Second, the qi and blood provide the material basis to maintain physiologic functions in the human body. The formation and metabolization of qi and blood ensure the functioning of zang-fu viscera and maintain human life activity. Meanwhile, the zang-fu viscera, in turn, boost the formation and metabolization of qi and blood. In that case, the coordination of zang-fu viscera centered on five zang viscera and bodily functions is realized.

Furthermore, spirit and physique act as two fundamental elements of life [20]. "Physique" refers to the body, including zang-fu viscera, channels, skin, veins, muscles, bones, essence, qi, blood, fluid, and other tangible substances. "Spirit" refers to our mind, consciousness, thinking, and other spiritual activities. Inseparable and interdependent, the spirit and physique form an organic whole, and the spirit and physique are

inseparable and interdependent. Thus, physical disorders can cause mental disorders and vice versa.

Therefore, when discussing the issues of human life, health, and disease, TCM not only emphasizes the microscopic whole with the five zang viscera as the center but also focuses on the interaction between the local and local, the local and whole, and the physique and the spirit. On the one hand, we can speculate the pathological changes of internal zang-fu viscera by the external pathological characteristics reflected on the physique, voice, tongue, and pulse, so as to make a diagnosis. On the other hand, the diagnosis of abnormal changes in the function of the zang-fu viscera can be assisted by observing a patient's mental state and the prevalence and decline of qi and blood.

2) Holistic View on Humans and the Environment: The integrity of humans and the environment is about human beings, the natural environment, and the social environment; together, they constitute a macrowhole with the human at its core.

First, the sunlight, air, water, temperature, magnetic field, and other elements in nature constitute the environment for human survival and reproduction [21], and all physiological activities and the metabolism of humans are subject to or dependent on the natural environment. On the one hand, the changes in the climate and solar terms regulate the changes in various body functions. On the other hand, the differences in the geographical environment and living habits also affect human functions to a certain extent. Human beings recognize the operation laws of nature through the process of their own physiological and pathological changes, and follow the laws of nature.

Second, the political, economic, cultural, legal, and other social factors in the social environment also affect the physiological and psychological changes of human beings. The level of social production and living conditions determines the level of human physiological and psychological health to a certain extent, especially the gap between rich and poor; the state of nutrition determines what kind of life attitude exists in individuals and what diseases they are prone to, while people also maintain the stability, balance, and coordination of their own activities in the process of understanding and transforming society.

Therefore, under the guidance of the holistic view, TCM treatment and diagnosis focus on both the microscopic whole of the human body itself and the differences in mental, emotional, and physiological functions caused by the natural and social environments in which people live [22], [23].

B. Holistic View in Deep Learning

Holism in the research of DL exists on different scales. Park et al. [24] regard considering the input data at the same time as holistic. Some others take exploiting parallelism through interoperator and intraoperator coscheduling as holistic to maximize hardware utilization. Few researchers decide to understand holistic DL in the big picture. Al-Amaren et al. [25] concatenate the residuals from different model blocks to output the result together. A more immense point of view
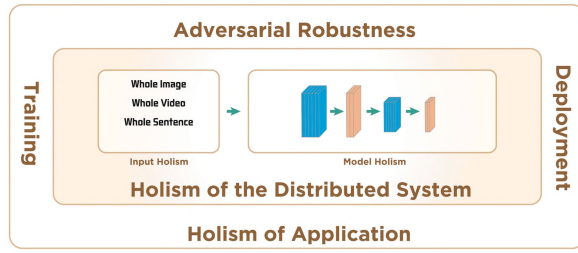
Fig. 3. Holistic view of DL. The concept of a holistic view in DL failed to reach a consensus. The holism, from recent papers, can be summarized as three levels, the model level, the distributed system level, and the application level.
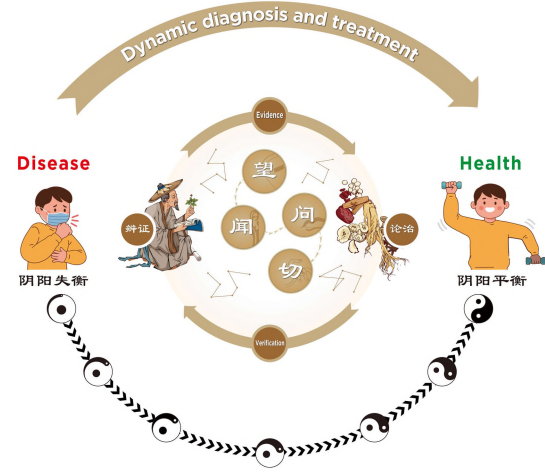

Fig. 4. Dynamic dialectical diagnosis and treatment in TCM. The figure shows the process of restoring the patient from imbalance to balance of Yin and Yang through syndrome differentiation and treatment under the guidance of the holistic view. Syndrome differentiation and treatment are the basic principles of TCM. Syndrome differentiation provides evidence for treatment, and the results of treatment can verify the correctness of syndrome differentiation. The essence of disease is the imbalance of Yin and Yang. The purpose of syndrome differentiation and treatment is to help patients restore the balance of Yin and Yang.

raises that holistic DL should optimize the learning process from data input to result output and consider the adversarial robustness at the same time that it could handle input data from various sources. However, no one has elucidated the DL model as an organic unity like the concepts in TCM, not even to mention the harmony between the model and the outer environment and society. The structures of holism in DL are shown in Fig. 3.

Despite all the above, what DL can learn from TCM, or in which content DL and TCM could be integrated together, is considering taking information from multifarious sources, in another word, being multimodal [26], just like TCM regards the five zang as one when diagnosing diseases. To be specific, TCM identifies the exact phenotype through the observation of the body, sound, and facial expressions, which could be considered as the fusion of physiological indicators, sounds, and images. Likewise, DL could process multimodal inputs [27], which also confirms the input holism. Current DL and even AI could not achieve the high realm of holism between humans and the environment, and only use the information from the environment [28]. Even so, the integration of DL could benefit the development of TCM. Meanwhile, with the consideration of DL, TCM can turn from a classic subjective and textual descriptive diagnosis into ITCM with the ability of objective and quantified diagnosis. In fact, some existing applications could be regarded as AI leveraging the holistic view from TCM; for example, snore sound, which is often used to detect sleeping disorders, could be used for indicating the status of the upper airway [29].

To sum up, the holistic view of TCM emphasizes the close link between the human body itself as an independent whole and the macrowhole composed of the human and the environmental component. As a practical medicine, TCM features an interpretable theoretical system and pursues vague reticular laws. For this reason, it is difficult to explain the mechanism of TCM clearly by means of modern medical analysis. DL features the ability to master the inherent laws and indication hierarchy of sample data, integrates data acquisition equipment, and realizes the visualization of the acquired information, such as text, images, and sounds during the learning process. However, there exists a black box aspect based on millions of weights learned to build highly nonlinear functions in DL, rendering the results largely nonexplicable. The data-driven DL can help TCM turn into quantitive and objective ITCM

under the guidance of a holistic view. Meanwhile, the holistic view can help DL unravel the "black-box" mechanism and accomplish multimodal data fusion.

III. TCM DYNAMIC DIALECTICAL DIAGNOSIS AND TREATMENT VERSUS ADAPTIVE LEARNING

Syndrome differentiation and treatment of TCM emphasize individualized and dynamic diagnosis and treatment. Adaptive learning is a process of data analysis, dynamic adjustment, result feedback, and continuous improvement of self-learning by using computers as interactive means in the process of understanding the development and change of things, which is consistent with the process of syndrome differentiation and treatment of TCM under the guidance of the holistic view.

A. TCM Dynamic Dialectical Diagnosis and Treatment

Syndrome differentiation and treatment are the basic principles of TCM to understand and treat diseases under the guidance of the holistic view, as shown in Fig. 4. It consists of two processes: syndrome differentiation and selection of treatment. Syndrome differentiation is a process of identifying the syndrome based on an overall analysis of symptoms and signs that are collected by the inspection, listening, smelling, inquiry, and palpation. The selection of treatment is a process of making a treatment plan based on syndrome differentiation and full consideration of the function of the zang-fu viscera, deficiency or excess of qi and blood, and environmental impact [30], [31].

Syndrome (证) is a dynamic response to diseases. It is capable of reflecting the essence and characteristic of the current stage of disease accurately [32], [33]. Thus, syndrome differentiation and the selection of treatment are interrelated and mutually influenced. Syndrome differentiation provides

the foundation for treatment, while the effectiveness of treatment can test the accuracy of syndrome differentiation. The process of syndrome differentiation and treatment is a dynamic process that changes according to space and time [34], which makes an individualized, dynamic, and precise diagnosis and treatment come true.

1) Temporal and Spatial Differences of Syndrome Differentiation Under the Guidance of Holism: The process of syndrome differentiation is a staged diagnosis of the dynamic change of disease development under the guidance of a holistic view. Syndrome differentiation is to identify the cause, nature, location, and current condition of the disease by analyzing and summarizing the symptoms and signs collected—as outlined above—through observation, listening, smelling, inquiry, and palpation [35]. Besides, the human body is a dynamic whole. The disease information of the body is constantly changing according to time and space [36], [37]. The syndrome is the summary of the pathological reflection of the body at a certain stage in the process of disease development [38], [39], while the process of syndrome differentiation is the concrete embodiment of understanding the temporal and spatial changes of disease. Since the microwhole of the human itself is different from the macrowhole formed by the human and its surroundings, the same individual or the same disease may have different types of syndrome at different stages, while different individuals or different diseases may share the same syndrome type at a particular stage. The process of syndrome differentiation highlights the scientificity of treating the same diseases with different methods and treating different diseases with the same method (同病异治, 异病同治), and as quoted from *Suwen Wuchangzheng Dalun* (素问·五常政大论), and shows advantages of precise and dynamic diagnosis and treatment of TCM under the guidance of the holistic view [38], [39].

2) Temporal and Spatial Differences of Deciding on the Treatment Under the Guidance of Holism: The selection of treatment is to decide on the corresponding treatment according to the results of the syndrome differentiation and also taking full account of patients' individual conditions. With the progress of treatment, symptoms will change accordingly. The selection of treatment depends on the result of the syndrome differentiation, and the dynamic treatment based on the time–space difference is of higher clinical value [40].

The major clinical treatment of TCM includes Chinese medicine and acupuncture. On the one hand, Chinese medicine prescription is mostly composed of multiple ingredients, in which each ingredient plays the role of "King/Monarch (君), Minister (臣), Assistant (佐), or Guide (使)," respectively, as written in *Shennong Bencao Jing* (神农本草经), and complements each other into an organic whole. With the change of syndrome, prescriptions need to be modified accordingly, which reflects the dynamics in syndrome differentiation and treatment. On the other hand, acupoints should also be selected according to the results of syndrome differentiation, rather than being limited to a single meridian or single acupoint. The prescription of acupuncture also needs to change according to the results of syndrome differentiation. To sum up, syndrome differentiation and treatment are diagnosis and treatment by

TCM characteristics under the guidance of the holistic view and are a pattern of precision medicine, which varies the formula according to the dynamic changes.

B. Adaptive Learning

Armed with advancements in data science, AI, ML, and adaptive learning are on the cutting edge of a dramatic change.

AI-Powered Adaptive Learningo: Classic ML methods generally train their models with fixed datasets; in other words, they are offline learning in a stationary environment. Whether seeking a visionary future for AI or addressing concerns about its application, progress should always be driven with a human-centered perspective—that is, one that allows taking a holistic view of AI systems while focusing on specific aspects, such as dynamic data or the environment. However, with previous AI models, it is not feasible to recollect and organize data, and retrain previously learned models as the environment changes [54].

Adaptive learning emphasizes the active adaptation of the learning environment and the learner. In a data-driven context, an adaptive learning system is an important carrier for big data collection, analysis, and personalized AI services [52]. In the adaptive learning process, the learning environment, content, and format should remain adjustable and continuous. Therefore, the core of an adaptive learning system is data collection, model analysis, and feedback. To this end, adaptive learning can leverage multiple methods to understand the multidimensional impact of environmental factors, which provides ideas for understanding human-centered AI from a holistic view.

1) *Multimodal Data-Driven:* Data-driven refers to a decision support method that takes data as the dominant factor. From a broad perspective, all behaviors are data-driven. From a narrower perspective, the opposite of data-driven is experience-driven. AI-powered adaptive learning will facilitate the transformation of limited static databases into dynamic open big data. With big data, all human behavior, thoughts, and experiences are represented as data that can be recognized by computers, thus addressing the human experience required for AI. For example, medical big data are facilitating the rapid development of medical diagnostic technology.

2) *AI Model Dynamic Adjustment:* Adaptive learning approaches have attracted much attention for their ability to provide more personalized learning. Now, adaptive ML is becoming more refined and effective, thanks to leaps in cloud-based managed services, computing power, and ML. Furthermore, the idea of adaptive has been combined with other ML methods, as shown in Table I. Therefore, adaptive learning and AI techniques complement each other.

3) *Adaptive Negative Feedback:* New AI-powered adaptive systems can provide adaptive feedback to help guide learners toward accuracy and keep them moving forward, so they do not get stuck in a frustrating loop. As to adaptive ML for changing environments, it was thought that, with continuous closed-loop feedback,

TABLE I
ADAPTIVE ML AND APPLICATION SYSTEMS FOR CHANGING ENVIRONMENTS

Research Areas	Aims	Methods	References	Description
Adaptive Machine Learning	Developing adaptive ML techniques that can adjust and guide the design, construction, and maintenance of a holistic view of AI systems. In addition, with the utilization of DL methods, the key factors for successful applications are sufficient datasets and dynamically changing environments, which are generally not readily available, especially in the medical field.	Ensemble Learning	Freund and Schapire [41]; Wang et al. [42]	AdaBoost (Adaptive Boosting) is adaptive in that subsequent weak learners are tweaked in favor of those instances misclassified by previous classifiers.
		Transfer Learning	Reeve et al. [43]; Vrbančič and Podgorelec [44]	In transfer learning, inference is made about a target task when having access to data both from the distribution itself, and from a different, but related source distribution.
		Deep	Xie et al. [45]; Taylor et al. [46]; Kim and Rhee [47]	Practical applications of supervised DL have achieved impressive results in recent years, but challenges remain in cross-domain environments.
		Small-Sample Learning	Daneshmand et al. [48]; Bang et al. [49]	For many ML problems, data is not abundant. To quickly notice changes in the environment and to continuously adapt the learning model accordingly is required when based on a limited number of data samples.
Education Expert System	Design AI-enabled learning systems to solve specific learning problems and improve the user learning experiences.	Literature Review	Imhof et al. [50]; Patil and Naqvi [51]; Kabudi T et al., 2021 [52]; Andersen et al. [53]	Adaptive learning education expert systems are personalized learning platforms that adapt to students' learning strategies, the sequence and difficulty of the task abilities, the time of feedback, and students' preferences.
MedicalExpert System	An adaptive medical system integrates learning, association, recognition, and information processing and is able to acquire knowledge by itself for self-learning.	Literature Review	Lan and Zhang [54]; Lu et al. [55]; Saibene et al. [56]	Medical expert system applications provide physicians and patients with an immediate access to knowledge and advice, rooting their flexibility into their knowledge bases, rule sets, and graphical interfaces [57].

online updates could be made with due attention to outliers and biases, thus making a classifier stronger. In summary, adaptive ML methods are necessary for closed-loop solutions.

To sum up, one should apply data-driven adaptive learning to the process of differentiation and treatment of TCM and reproduce the process of individualized syndrome differentiation of TCM through the comprehensive analysis of the human body's own state and the relationship between people and the external environment in different temporal and spatial dimensions, which can provide more objective evidence support for the differentiation and treatment of TCM. At the same time, one should improve the process of individualized treatment of TCM through a combination with the dynamic adjustment mechanism and feedback mechanism of adaptive learning, which makes individualized, dynamic, and precise diagnosis and treatment come true.

IV. HOLISTIC VIEW VERSUS FIELD THEORY

The holistic view of TCM and the field theory are dialectically unified in ideology. There are many fields existing in the human body, such as the psychological field, magnetic field, and further more. The fields' changes in the human body can reflect the internal response of the human body to the external environment and the changes in the internal systems of the human body, which provides new diagnosis and treatment thinking.

A. Holistic View

The holistic view of TCM holds that everything in the world is interconnected, which coincides with the field theory, which considers the field as a whole of interdependent coexistence facts [58]. On the one hand, with the human body being a field, the body and the spirit are important components of the field. On the other hand, the human being and the environment also form a field together, where the human being and environment are interdependent [59].

The holistic view of TCM is centered on the theory of Yin and Yang, which is a unique way of thinking based on ancient materialistic dialectics, such as the Yin and Yang theory, the meridian theory, and the essence-qi theory [60]. The Yin and Yang theory holds that Yin and Yang are not only mutually exclusive but also mutually reinforcing and complementary, which is consistent with the interdependence theory of field theory, as quoted from *Suwen Yin and Yang Yingxiang Dalun*. Fig. 5 shows the basic concept.

1) Yin and Yang Unite All Things in the World: As already laid out above, Yin and Yang represent interrelated and opposite things or phenomena in the universe or two opposite aspects within the same thing. According to the property, tendency, and position of things or phenomena, and through mutual comparison, TCM summarizes attributes of Yin and Yang: all the moving, extroverted, ascending, diffuse, warm, bright, and exciting ones belong to Yang; and all the relatively static, inward-looking, downward-looking, condensed, cold, gloomy, and restrained ones belong to Yin. It follows that everything in nature objectively has two opposing aspects, so, in that way, Yin and Yang combine to form all things in the world [61].

The theory of Yin and Yang is widely used in all aspects of TCM, and as mentioned, TCM holds that the imbalance of Yin-Yang is the root cause of diseases, which had been discussed in *Suwen Shengqi Tongtian Lun* (素问·生气通天论).
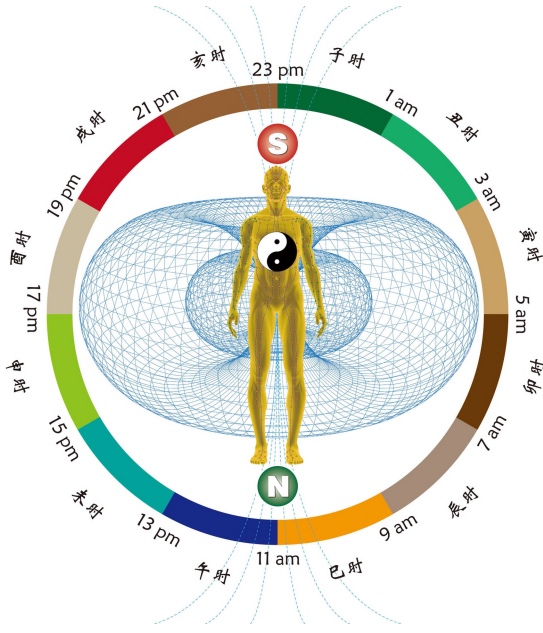
Fig. 5. Holistic view of the human and the environment. The figure shows that the human body is a field, while the human being and the environment also form a field together. These fields emphasize the connection between things, which coincides with the theory of Yin and Yang in TCM. These fields can be visualized and quantified with the computer or other tools for observing the holistic change trend.

On the one hand, changes in the balance of Yin and Yang in the human body can lead to changes in the zang-fu viscera, qi and blood, and meridians, causing disease. On the other hand, when the balance between the human body and the natural and social environment is disrupted, it will also lead to changes in the zang-fu viscera, qi, and blood, and eventually lead to diseases. Therefore, TCM focuses on restoring the balance of qi and blood, and the functions of the zang-fu viscera through syndrome differentiation and treatment to achieve a state of balance between Yin and Yang [62].

2) Unity of Meridians and Fields: Meridians and collaterals are important regulating channels carrying qi and blood and maintaining functional balance in the human body. Meridians link the interior and exterior of the human body, and collaterals crisscross all over the body, connecting the viscera, body, and orifices into a unified functional whole [63], [64]. On the one hand, meridians and collaterals are interdependent, forming an organic whole vertically and horizontally, which coincides with the field theory [65]. On the other hand, there is also an interdependent relationship between meridians, such as the bladder meridian of a foot greater yang (**BL**, 足太阳膀胱经) and the kidney meridian of a foot less yin (**KI**, 足少阴肾经), which are two meridians outside and inside each other, as quoted from *Lingshu Jingmai* (灵枢·经脉). Therefore, when treating enuresis in the clinical treatment of acupuncture, we can simultaneously select a Weizhong point (委中穴) of BL and a Taixi point (太溪穴) of KI, which illustrates the way of matching the exterior and interior and combining Yin and Yang to treat diseases.

B. Field Theory

The field theory is a method to analyze the relationship between substances, which is consistent with the holistic view.

In the 19th century, James Clerk Maxwell introduced the displacement current creatively based on the four experimental laws of electricity and magnetism found by Charles Augustin de Coulomb, Carl Friedrich Gauß, André Marie Ampère, and Michael Faraday [66]. Maxwell's equations are a great synthesis of previous work. At the same time, Maxwell et al. [66] first introduced the conceptual basis of field theory—the energy storage field. The field theory affects people's understanding of nature [67]. A magnetic field also widely exists in the human body. McFadden [68] explored how the conscious electromagnetic information (CEMI) field theory describes consciousness. Magnetoencephalography (MEG) is a kind of brain function detection technology for noninvasive detection of brain electromagnetic physiological signals, which can help people understand dynamic cognitive processes and the generation process of mental disease [69], [70]. The four familiar Maxwell's equations were derived by Hertz in 1890 [71], [72]

$$\nabla \cdot \boldsymbol{D} = \rho \tag{1}$$

$$\nabla \cdot \boldsymbol{B} = 0 \tag{2}$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t} \tag{3}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} + \frac{\partial \boldsymbol{D}}{\partial t} \tag{4}$$

where $\boldsymbol{D}$ is the electric displacement, ρ is the density of a free electron, $\boldsymbol{B}$ is the magnetic flux density, $\boldsymbol{E}$ is the electric intensity, $\boldsymbol{H}$ is the magnetic field intensity, and $\boldsymbol{J}$ is the conduction current density.

The psychological field represents the characteristic of individual activity. Lewin [73] first introduced the concept of the "psychological field," As described by Lewin, a person's behavior depends on the interaction between the individual and the cultural environment. The formula of the psychological field can be expressed as follows:

$$b = f(p \cdot e) \tag{5}$$

where b is the individual behavior, p is the individual attribute, e is the cultural environment, and f represents a function. This indicates that all behaviors of individuals change with themselves and their environmental conditions. The construction of the psychological field is affected by two factors: "life space" and "behavior motivation." With the development of a collection system of human psychological and physiological data, more and more research on psychology has been carried out in other fields. Many researchers pay attention to a (vehicle) driver's psychological activities. The driver's psychological activity is the direct receptor of man, vehicle, road, and environment interaction. The drivers' perception of the surrounding environment can be quantified by establishing the equipotential lines of the driver's psychological field [74], [75], [76]. Consumers' purchase decisions can also be analyzed by field theory [77], [78]. Similarly, field theory can be taken as a framework to appraise children's momentary state of curiosity and exploratory behavior [79]. What is more, Hu et al. [80] share the perspective to model mental status quantitatively based on field theory, which further expresses the importance of field theory research.
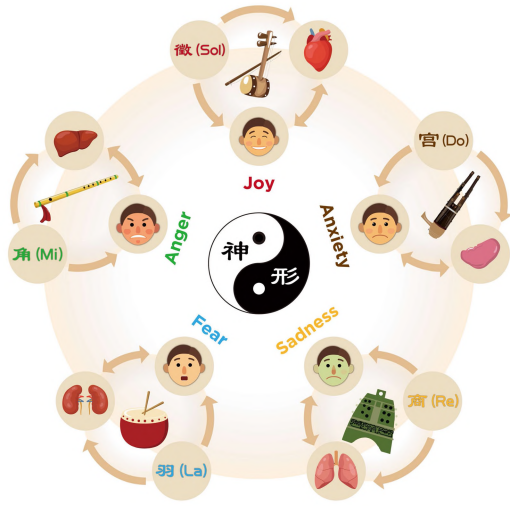
Fig. 6. Relationship among the five minds, five zang-viscera, and five notes. The figure shows that the five minds, the five zang-viscera, and the five notes are associated and mutually influenced, which shows the inseparability of the body and mind under the guidance of the holistic view.

Explainable AI (a.k.a. XAI) aims to make people comprehend the decision-making process of an AI-based system [81] and is also significant in biomedical engineering. The field theory is highly interpretable as it can represent the characteristics of space through physical attributes. Ren et al. [82] show that visualization is regarded as a promising method for realizing the representations of features. The dynamic process of a field is visualized with the computer or other tools for observing the holistic change trend and discovering the unique features.

V. HUMAN-CENTERED TCM VERSUS AFFECTIVE COMPUTING

One of the concepts of affective computing is to recognize the emotions of human beings, while the holistic view of TCM contains the five minds (五志) that reflect the affects. Affective computing uses the multimodal fusion method to reproduce the relationship among the five minds, five zang-viscera, and five tones, and assists in the realization of music therapy.

A. Human-Centered TCM

The holistic view of TCM holds that the human is a unity of the body and the spirit. The emotions are in accordance with the zang-fu viscera. Thus, the spirit and emotions are closely related to the occurrence, development, and treatment of diseases. TCM doctors highly valued the spirit and emotions, which also shows the human-centered perspective of TCM.

1) Emotions' Accordance With the Zang-Fu Viscera: The holistic view of TCM in emotion is embodied in the internal relations of emotions and their relation to zang-fu viscera.

First, the emotional activities can be regarded as a unified whole [83]. TCM summarizes emotional activities as "five minds," as shown in Fig. 6, which consists of anger, joy, anxiety, sadness, and fear. Among them, mutual restriction exists. For instance, sadness can restrict anger. Second, five minds and five zang-viscera form a unity together in which

an association mapping exists between emotions and zang-fu viscera. That is, in the TCM theory, for example, the anger in five minds is related to the liver in zang-fu viscera. The abnormality of emotions will affect the zang-fu viscera, and vice versa [84], [85].

Under the guidance of the holistic view, TCM has formed a unique emotional therapy. On the one hand, based on the mutual restriction among emotions, emotions can be used to restrict other abnormal emotions [86], [87]. On the other hand, based on the association mapping between the five minds and the zang-fu viscera, emotional diseases can be treated by regulating the zang-fu viscera, and the treatments for emotional damage can be helpful in the recovery of the zang-fu viscera. In addition, in the five-phase theory of TCM, the five minds are in accordance with "five notes" (五音), namely, Do (宫), Re (商), Mi (角), Sol (徵), and La (羽). Anxiety, sadness, fear, anger, and joy are, respectively, related to the tones of Do, Re, Mi, Sol, and La. TCM, hence, has it that choosing appropriate music according to different emotional states can temper and soften the emotion to prevent and treat diseases [88], [89].

2) Concept of Holism of Inseparability of the Body and Mind: The theory of holism of inseparability of the body and mind (形神合一) in TCM holds that the body and the spirit are closely related and mutually influenced. A healthy body benefits the spirit, and vice versa, as discussed in *the Simple Questions Shanggu Tianzhen Lun*. Therefore, in the prevention and treatment of the psychosomatic disorder, TCM attaches equal importance to regulating the body and the spirit, and emphasizes the correlation between the two. Thus, it strives for the unity and harmony of the body and the spirit [90], [91], [92], [93].

B. Affective Computing

Affective computing is the research in computing that "relates to, arises from, or influences" emotions and is a cross-disciplinary study with the interaction of psychology, computer science, and cognitive science [94]. The aim of affective computing is to recognize, interpret, process, and simulate human affects. The related topic of emotion was discussed in the early development of philosophy, but the concept of modern affective computing was first introduced by Picard [95] in the year 1995.

The development of affective computing mainly focuses on the following two aspects.

1) *Perceiving Affect*: Most current affective computing studies focus on the perception of human affect. Computers or models are trained to perceive the affective state of a human, and to give a response is rendered possible.
2) *Expressing Affect*: This is perhaps the most challenging technology, and the development is still in its early stage. Related intelligent devices can provide an affectively proper reaction to their users, which is hoped to make the users feel more comfortable.

The research fields in affective computing include acoustic and textual affect analysis, facial expression recognition,

body gesture, and affective movement recognition, multimodal systems, affect understanding and cognition, and according to affect generation. Meanwhile, affective computing still faces the challenge of affection by real environment and handling of multiagent systems, among others. One of the most recent research on affective computing is computational psychophysiology and its inverse problems [97] proposed by Hu et al. [96], which can quantify the psychological state of people through their physical signals.

In general, TCM considers only the precision of a diagnosis and the performance of a treatment—it merely focuses on the affect changes in the patients. As outlined, TCM describes the affect of humans as "five minds," and they are related to the five zang. Affective computing can help reveal the hidden connection between the "five mind" and the "five zang." One step further, there are early since many studies on affective computing considering multimodal fusion [98]. These studies could meet the holistic view of TCM by using the heart sound, lung sound [99], and physiological indexes of blood (liver) and urine (kidney). The multimodal data could also include further information, such as facial expression images. Last but not least, from the healing point of view, music intervention can be regarded as the holism proof of the five notes and five minds.

VI. CHALLENGES AND OPEN ISSUES

In summary, there are three main biggest challenges or open issues that need to be tackled urgently for ITCM.

A. How to Establish Explainable Models for Learning High-Level Representations From the Multisource Heterogeneous Data?

DL features the ability to master the inherent laws and indication hierarchy of sample data, integrate data acquisition equipment, and realize high-level representations of the acquired information, such as text, images, and sounds during the learning process. However, as mentioned above, its "black box" characteristic renders results mostly not explicable. As a practical medicine, TCM has an interpretable theoretical system and pursues vague reticular laws. For this reason, it is difficult to explain the mechanism of TCM clearly by means of modern medical analysis. Interpretable AI technology is an effective way to solve this problem. However, so far, interpretable AI has been an outstanding issue. On the one hand, most of the existing interpretable AI approaches focus on post-hoc explainability, i.e., instead of building interpretable model architectures, the impact of various features on the results is quantified or approximately quantified by various postprocessing methods. Moreover, the requirements for interpretable results for users are still strict. That is, they need to master certain mathematical and computer knowledge, which may not be too difficult for non-TCM doctors, but it may be difficult to popularize the current interpretable AI methods in this special group of TCM doctors. On the other hand, to the best of our knowledge, present interpretable AI methods are largely designed for single-modal and single-source data, and do not sufficiently address studies for multisource heterogeneous data. Multisource heterogeneous data will increase the complexity of high-level feature representations and models, creating new challenges for model interpretability. To this end, under the guidance of the holistic view of TCM, the establishment of a knowledge-driven DL algorithm is helpful to transform the abstract TCM theory into objective and quantifiable evidence resources, and break the blind box characteristic of DL algorithms.

B. How to Extract the Multimodal Information via the Power of Intelligent Traditional Chinese Medicine?

In the last decade, single modal as a paradigm has been extensively studied. Yet, there has been a shift from single-modal information to multimodal such. Multimodal information learning refers to finding a unified representation of multimodal data through the information of each mode. Multimodal information learning can aggregate information from multisource and multimodal data, allowing a model to learn a more complete representation. Until recently, however, most multimodal information representations just involved simple concatenation of single-modal representations. In the computer field, single-modal information is generally represented by a vector (series), representing an image, an audio sample, a single word, a sentence, and the like. However, it is the key question whether the values of each dimension can have good properties. For example, for ITCM diagnosis, the information similarity of speech [100] and facial expression learned is very important, i.e., the representations (vectors) of different modalities' information from the same person should have a higher degree of similarity. In addition, how to deal with different levels of noise is also a challenge because the noise generated by different modalities is different.

C. How to Explore Novel Ways for Diagnosis and Treatment by Intelligent Traditional Chinese Medicine?

1) Precondition—A Standardized ITCM System: TCM information of diagnosis and treatment is complex and diverse, while data are one of the key concepts in AI. The precondition of ITCM is to establish a standardized system and build a normalized database that contains the basic concepts of TCM.

2) Foundation—Clinical Information Collection: The foundations of diagnosis and treatment in TCM are the four diagnoses (look, listen, question, and feel the pulse) based on doctors' subjective views and experiences. The first step to implement ITCM is, with the guidance of a holistic view and leveraging AI technologies, to achieve an objective, digital, and normalized data collection and labeling of four diagnoses.

3) Assisted Decision-Making: Dynamic dialectical diagnosis and treatment, as the distinctive feature of TCM, form the basic principle of how TCM understands and cures diseases, and manifests the flexibility of clinical diagnosis and treatment. By leveraging AI simulating and modeling clinicians' experience and/or TCM "classics," the process of personalized dynamic syndrome differentiation and treatment can be reconstructed. A precise ITCM model can be achieved with the iteration of optimizing the considered intelligence algorithm. Besides, the therapeutic effect is the precondition of

the development of medicine, while the therapeutic evaluation criteria of TCM are just patients' subjective feelings and clinicians' clinical experiences, which are lacking in objective quantification. However, AI offers new evaluation and analysis methods, such as computing affect changes through observation of the physical field, to objectively quantify the therapeutic evaluation, which can assist ITCM clinical decisions.

4) Application—Scenario Expansion: The expansion of TCM is restricted by the clinicians' ability and the "face-to-face" diagnosis between a clinician and a patient. However, ITCM can expand itself to new treatment models and new application scenarios, such as distant diagnosis and treatment. ITCM can also realize human–machine interaction with AI technologies. ITCM develops intelligent devices and clinical decision systems to serve the four diagnoses: inspection, listening and smelling, inquiry, and palpation and syndrome differentiation and treatment. In that way, it may facilitate or even partially take the place of doctors in the diagnosis and treatment process.

D. How Could Holistic View Promote ITCM?

At present, "data-driven" is still the main mean of AI technology, but, with the continuous deepening of the application of AI technology in the complex medical scene of TCM, more and more studies show that the "data-driven" AI technology can no longer meet the current needs for the intelligence development of TCM. From "data-driven" to "data-driven" and "knowledge-driven," through the integration of multiple technologies, such as DL and knowledge maps, the causal and logical relationships in a large number of knowledge data are comprehensively utilized. This is expected to help improve the cognitive ability of AI and realize true "intelligence." TCM has formed a complete knowledge system through thousands of years of development. The theory of Yin and Yang (阴阳学说), the theory of five elements (五行学说), and the theory of five viscera (五脏学说) all reflect the rigorous and meticulous logical thinking of TCM; however, due to the lack of objective "entity" research in TCM, its theory has a certain degree of abstraction, which has become the key problem to be solved urgently in TCM. The integration of medicine and industry has not only found a breakthrough method for scientifically clarifying the principles of TCM but also provided theoretical support for improving the algorithm decision-making ability of AI, which will help the intellectualization of TCM move forward to objective and accurate ITCM.

VII. CONCLUSION

In this survey article, we first introduced the concept of a holistic view of TCM in terms of its origination, development, and applications in the emerging field of ITCM. In order to make a comprehensive comparison between the methodology in TCM and AI, we further introduced and discussed a holistic view of DL, adaptive learning, field theory, and the idea of affective computing. We intended to not only present interesting research directions toward the state-of-the-art work but also presented insights and perspectives by

sharing current challenges and open issues. In summary, this is the time coming to ignite the dawn of "neo-traditional" Chinese medicine development by introducing inspirations and paradigms from modern intelligent information technologies.

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