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An Interactive Task Analysis Framework and Interactive System Research for Computer Aided Diagnosis

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ABSTRACT Computer aided detection and diagnosis system (CAD) is designed to improve the efficiency and quality of medical diagnosis. The existing CAD system tries to realize a diagnosis process in an automatic way to replace the doctor's diagnosis work completely, but it is difficult to capture the doctor's detection and diagnosis needs and goals accurately due to lack of doctor's experience. Thus, the accuracy is not up to the doctor's manual diagnosis results, and it is a tedious and cumbersome job to use the system because it requires manual intervention, which leads to the fact that CAD system was difficult to be widely used. This paper analyzes the characteristics of doctors' diagnosis tasks deeply, and makes the reasonable allocation of tasks between the doctor and computer. Then the perceptual control theory is introduced into the task model, a PTT task model is proposed to make it express uncertainty of the doctor's diagnosis tasks, and it can be used as a reference for future uncertainty task analysis. Therefore, an interactive CAD tasks framework is put forward with the assistant decision support provided for doctors by means of Bayesian network model and conceptual graph semantic matching method to diagnose tasks. In addition, effective support is provided for interface development staffs to design interactive systems that are suitable for the physicians' diagnostic tasks. The experimental results show that the method not only improves the accuracy and efficiency of the medical diagnosis, but also improves the usability of the system design.

INDEX TERMS Computer aided detection& diagnosis, task model, perceptual control theory, human-computer interaction.

I. INTRODUCTION

With the development and application of medical imaging technology such as X, CT, MRI, optical ultrasound, and PET, Computer Aided Detection & Diagnosis (abbreviated as CAD) system makes doctors diagnose the disease more conveniently. In recent years, the accuracy of CAD system has been widely concerned and studied. Some automated CAD systems have been proposed to attain high classification performance and obtain higher accuracy using a variety of machine learning-based techniques, such as combining the fuzzy base systems and evolutionary genetic algorithms, processing ensemble under-sampling for imbalanced data, and combining texture, shape, and kinetic curve features to differentiate benign from malignant tumors [1]–[5].

The current CAD system, which is based on a variety of self-learning algorithms to design, has basically achieved the purpose of automatic diagnosis. However, it still can not reach the cognitive and perception abilities of human beings. Moreover, it can not make accurate judgments for many foci, and still needs the doctors' manual diagnosis, which leads to doctors' additional workloads, so the CAD system was abandoned by the doctors. Experience shows that fully automated CAD systems are not accepted by people.

Interactive CAD systems have been proposed to improve the doctors' work efficiency and accuracy. Moon et al. determined the descriptor of breast lesions by analyzing the radiologist's report, defining the feature selection criteria for CAD development and reducing the time complexity [6]. Wang *et al.* [7] used the online payment method to vote on the task of pulmonary nodules, combined with CAD system screening cases to do the fusion, the results show that the human-computer intelligent convergence system is better than the diagnostic ability of doctors and traditional CAD system level. There are also scholars using virtual reality to increase the doctors' diagnosis or natural interaction in the process of surgery [8]. However, the system can not achieve the true sense of the human-computer cooperation and complementary advantages.

In order to overcome the problems of the fully automated CAD system, it is necessary to introduce doctors' interaction into the CAD system. Tasks are assigned reasonably based on the expertise of doctors and computers, and divided into high-level feature tasks and low-level feature tasks accordingly. The low-level feature tasks can be accomplished by computing, and the high-level feature tasks which are accomplished by doctors will be judged by the human perception and cognition. Therefore, design of interactive CAD systems is a potential feasible solution to solve the above problems in the existing CAD system.

Task analysis is a key point to explore the interactive CAD system requirements. By understanding the process and the goal during doctors' performing the goal, task analysis structures and logically analyzes the organization of the data collected during the actual implementation of the task, so as to get the task model.

The process of task analysis is the task of modeling [9], [15]. As the present analysis and modeling method of the task, HTA (Hierarchical Task Analysis), GOMS (Goals Operators Methods Selectors), and CTT (Concurrent Task Trees) are not suitable to express the uncertainty of the relationship between the subtasks [9]–[14]. Tim Clerckx improves the CTT by introducing decision points into CTT to adapt to the needs of mobile dynamic task context modeling, but it is suitable for the users of general context changes, due to the lack of cognitive analysis of the task of doctor diagnosis. Therefore, it can not be directly applied to the medical diagnosis tasks [14]. Symptom is a manifestation of the external reflection of the doctor through visual observation. Doctors diagnose the disease through the symptoms to determine what disease patients are suffering from. The situation that the same disease with different symptoms, or the same symptom with different diseases is often encountered in the process of medical diagnosis tasks. Different doctors may have different decisions even with the same symptom, which leads to the uncertainty in the process of performing the tasks. From a psychological point of view, the task that the users need to complete using structured cognitive model and stimulus response model to describe in static environment in general. The structured cognitive model regards that all behaviors have been planned in advance without considering the change of the external factors. The stimulus response model considers that all the behaviors are produced by the stimulus, and the same stimulus will get the same results without considering how to reach the target task [15], [16].

Therefore, this paper combined the respective advantages of HTA, CTT and PCT (Perception Control Theory) with the dynamic characteristics of DynaMo-AID model, and improved CTT to present an interactive task analysis model, which was Perception Task Trees (abbreviated as PTT) model for doctor diagnosis and interactive CAD system framework. This paper derived the dialogue model with the availability of rational allocation between the human tasks and computer tasks, and applied PPT in task analysis to guide the development of interactive CAD system with availability. In addition, the task model provides a reference for the uncertainty task analysis in other fields.

According to the fact that preliminary diagnosis results were derived features, a Bayesian network model is built by medical experts' knowledge. Moreover, by combing vector space model and semantic concept map with retrieval, similar diseases can be searched based on input cases. Through the above decision, doctors can diagnose the decision-making task. For the low seniority of the doctor, they can improve diagnostic accuracy and efficiency of diagnosis.

II. RELATED WORK

A. TASK MODEL

At present, there are two task analysis methods: hierarchical task analysis methods and functional task analysis methods. The hierarchical task analysis is a structured approach, which decomposes the tasks hierarchically, refines user tasks step by step until the specific operation to describe the hierarchical relationship and the relationship between subtasks. In the process of decomposition of the task, the users will clearly understand the implementation details of product. The earliest hierarchical task analysis is HTA model, from which the subsequent hierarchical task analysis methods are derived.

CTT can be used to express the rich semantic and task model with graphic symbols. It is the combination of the static hierarchical model and dynamic function model, which not only embodies the hierarchical relationship between tasks, but also expresses multiple temporal relations between tasks such as the sequence, the selection, and the concurrence. CTT divides tasks into 4 types: abstract tasks, user tasks, application tasks, and interactive tasks [9]–[11].

The use case model belongs to the functional task model. The use case, the role and the system are the basic elements of the use case model. It is a macroscopic description of the function of the system, which can help users to analyze and understand the behavior of the system.

The temporal relationships that the hierarchical task models such as HTA and GTA describe between tasks are designed in advance. Although CTT combines the dynamic

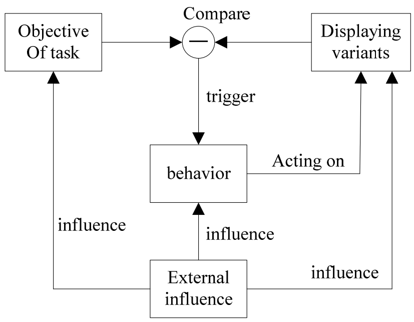

FIGURE 1. The relationship between the elements of based on PCT task model.

features of function model, it does not take into account how to achieve the task goal. The use case model is the description of tasks from the functional perspective, and cases are independent from each other.

PCT is a new control theory originally proposed by the medical physics expert named Willian T. Powers, who developed systematically the control theory and biological control theory, and also gave a more thorough and complete explanation of human behavior, cognitive process and cognitive mechanism of human and other animals by using the control theory model [15]. PCT argues that there is a feedback between the independent survival of the organism and the environment, whose behavior is affected by environmental variables, and is based on the process of controlling the specific objectives. The task model based on PCT considers the characteristics of needs of users and the uncertain factors to describe the tasks from the 4 aspects as follows [16], the user's task goal, external influence, behavior and display variables, and the relationship between the various elements as shown in FIGURE 1.

B. CONCEPTUAL GRAPH

Conceptual graph [21], [24], the theory of which is based on the predicate logic, is a knowledge representation tool that describes the structure of complex objects, which can be completely translated from the natural language and express the semantics of the natural language completely. Compared with first-order predicate logic, descriptive logic, and semantic network, conceptual graph has a more direct mapping between natural language, graphical representations are more readable and intuitive than logical formulas.

Definition 1: If a conceptual graph u can be generated from the conceptual graph v through a series of formal rules, then u is called the specialization of v, or v is called the generalization of u, denoted by $u \leq v$.

Definition 2: Let u and v are two conceptual graphs, If $u \leq v$, then there is a subgraph u' of u, which is isomorphism to v, i.e., $u' = v \rightarrow u$, called v on the projection of u.

The matching of the two conceptual graphs can be divided into the following two cases [24]:

1) matching by projection.

Theorem 3: If $u' = v \rightarrow u$, then the following three holds:

a. The relationship between the concepts of u' and v is the same.

b. If the relationship r in v is attached to two concepts d_i and d_j, then r is connected to concepts c_i and c_j in u.

2) matching by maximum connection.

The maximum connection is a connection on the largest expanded compatible projection, which is the connection on the largest connected subgraph part of the two original graphs. The matching algorithm of maximum connection is as follows:

a. Doing the following loop iteration for each relationship in v:

If r is not in u, then search for the next relationship; otherwise, suppose that c_1 and c_2 are two concepts associated with r in u, d_1 and d_2 are two concepts associated with r in v. If c_1 and c_2 are compatible, c_2 and d_2 are compatible, then the relationship (r, e_1, e_2, -) is placed in the result graph.

Here, e_1 is the largest common subtype of c_1 and d_1, and e_2 is the largest common subtype of c_2 and d_2; otherwise, go back to step a.

b. connect the remaining part of v to the result graph.

c. connect the remaining part of u to the result graph.

In [24], the proposed projection matching and maximum connection matching are incomplete matching, which can increase the reasoning and prediction ability of conceptual graph. However, when the above two matching methods are not successful, we will use semantic computing method to achieve the purpose of matching two graphs in this paper.

III. PTT MODEL

The physician's diagnosis task has the following characteristics: generality and particularity. Generality means the diagnosis task can be decomposed into a number of subtasks, which indicates that the task has a hierarchical feature. Particularity is embodied in the dynamic and uncertainty of the decision making process of the doctor's diagnosis tasks. According to the patient's symptoms, the process of the doctor making a decision is a perception control process, and the doctor adjusts his or her behaviors according to the change of external factors to achieve the established objectives ultimately.

Most deterministic tasks can be decomposed into a number of subtasks, and the relationships between the subtasks have been identified in advance without changing with the external factors, so these tasks can be described with hierarchical task model such as HTA. In the real world, there are some tasks which can not simply be described by the sequence, selection and other relationships. For the same diagnosis task of the same symptoms with different diseases, different doctors have different diagnostic results, which leads to the uncertain relations between the subtasks. Although CTT can express some certain dynamic characteristics, it has been determined by the design staffs before running stage, while the doctor's diagnosis task must be determined in the running stage by the user. The above models can not express the uncertainty of this dynamic task [16].

In the process of doctor's diagnosis, task target is the intrinsic image of the focal point formed in the brain of a doctor, which is related to the experience of the doctor's diagnosis. The display variables are the current focus sign and other examination results. The doctor compares the task with the display variables. According to the results, the behaviors of the doctor are triggered, whether the display variables (by other equipments such as CT, X and other light observe focus) are adjusted to continue comparing with the current task target (deny current assumptions to form a new focus image in the doctor's brain). External influence can be subjective consciousness or external disturbance. Therefore, the decision-making process of the doctor's diagnosis tasks is a perceptual control process.

The analysis process of the doctor's diagnosis task is to repeat comparing the task target with the displaying variables, and then keep close to each other by changing the task target or displaying variables. According to observing the clinical symptoms of the patient, the doctor first give a preliminary decision according to his or her own clinical experience, and then check the lesions according to his or her decision until the final diagnosis. Doctor's decision-making process and inspection are constant iterative processes, because the decision of the doctor with different seniority is dynamic and uncertain (different doctors may make different decisions). In the process of decomposing the doctors' diagnosed tasks, dynamic decision making is introduced. The uncertain tasks are executed by doctors with different seniority according to clinical experience, and the execution sequence of the other subtasks is performed according to the previous design.

Based on the HTA and CTT model, this paper introduces the PCT theory, presents a task model, i.e. PTT (Task Trees Perception) model in order to describe the dynamic and uncertain characteristics of the doctor's diagnosis task. The task model often describes the conceptual elements and the relationship of the task model in the form of a task ontology, i.e., a meta model, and many foreign literatures have expressed HTA, GTA and CTT meta-model by using class diagram. The PTT task meta-model is shown in FIGURE 2.

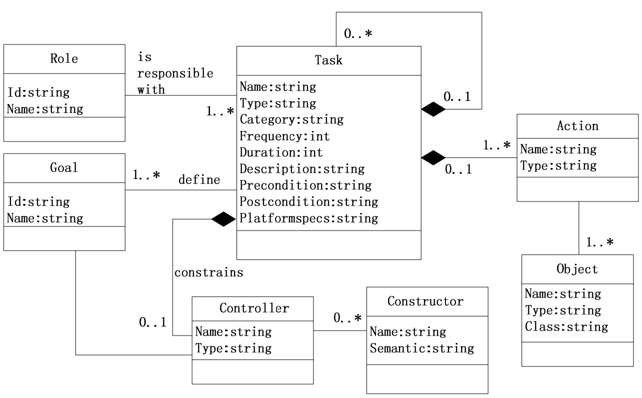

FIGURE 2. The meta-model of PTT model.

The PTT task meta-model uses the following conceptual elements to describe the task world: (a) task, which is the set of operation sequences that are executed to accomplish the goal; (b) role, which is the type of user executing the task; (c) goal, which is the state that the user wants the system to show after completing the task; (d) actions, which refer to a series of operations to complete the task; (e) controller, which defines the relationships between sub-tasks of the same hierarchy; (f) object, which is the content of a concrete operation.

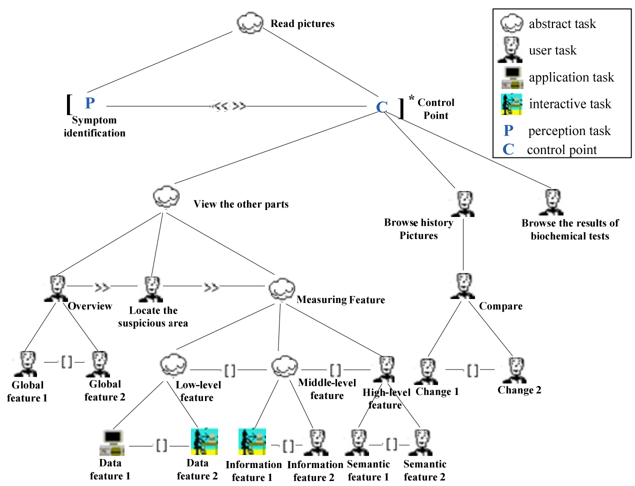

FIGURE 3. The PTT task model of Doctor reading pictures.

Based on the CTT model and the dynamic characteristics of the DynaMo-AID model [14]–[16], the perception task and the control point are introduced into the PTT task model as a task unit to support the dynamic characteristics of the diagnosis task. FIGURE 3 shows the structure of PTT task model that a doctor reads the picture.

Abstract task, which describes a complex task, can be divided into the following four tasks: user task, which describes the user's activities; application task, which is executed by the system; interactive task, which is completed by user and system through a series of interactive actions; perception task, which is high-level user decision-making activity. In addition, the introduction of control points indicates the uncertainty of the subtask temporal relationship. When a control point is encountered, doctors with different seniority and clinical experience can determine which task to perform. The perception task and control point are combined together to form the sense control unit, which determines the execution sequence of the dynamic task in the running stage. Perception-control is an iterative process. The perception task and the subtasks under the control point constitute an indefinite temporal relation. For the task P, the prerequisites are the same, but it is uncertain which task will be executed subsequently. Obviously, such a task is suitable for doctors with rich clinical experience to complete. The introduction of the temporal notation "≪≫" indicates the perception task and the control point form a two-way flow relation. The perception task can reach the control point, and the control point can reach the perception task, which expresses the iterative relationship between the two tasks. When the doctor checks the focus recognition of the symptoms, the first is the formation of an intuitive feeling that what kind of disease in the brain. The following possible decision is to check the other regions, which completes a ''cognitive-control'' process, and then returns to repeat executing ''cognitive-control'' according to the inspection results, which is a continuous iterative process until the final diagnosis.

As the input of the control point, the perception task is the output of the doctor's brain decision-making results to control which task to perform in the next step, so the process is dynamic. The perception task and the control point together determine the dynamic operation of the task, which is different from the choice and concurrence temporal relation in the CTT. Whether it is selective or concurrent, CTT can only represent one of the temporal relationships, and the user must only perform the task in accordance with the temporal relationship. In fact, different doctors make different decisions. PTT will decide the right to perform the task to the user, and these tasks can be in accordance with the order, selection, concurrency, etc., or skip these tasks.

IV. INTERACTIVE CAD FRAMEWORK

The intelligent algorithm of current CAD system can not capture the objectives of human task effectively, so the human factors are introduced into the CAD system. Interactive CAD design framework was proposed based on the PTT task model through in-depth study of the characteristics and work process of the diagnosis task. As shown in FIGURE 4.

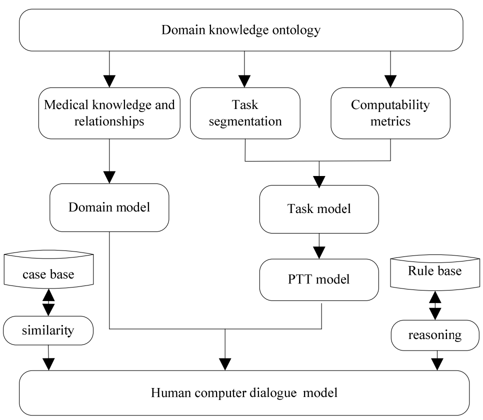

FIGURE 4. **Interactive CAD framework.**

The construction of domain knowledge ontology involves the medical terms and the relationship between them, which requires medical experts, psychologists, and artificial intelligence experts to participate in the completion, which is a standardized description of medical focus and structural organization. The domain model describes the relationship between medical knowledge, which is an abstract representation of concepts and relationships involved in the diagnosis task, and it is easy for developers to understand. By analyzing the process of doctors' diagnosis tasks, the doctors' diagnosis tasks are divided into several subtasks, and the subtasks are computed and analyzed to determine which subtasks are suitable for computer and which subtasks are suitable for doctors to complete. Task model is an abstract description of the partition of the doctor's diagnosis task and the relationship between the various subtasks. PTT model, which is based on the task model, the aim is to further analyze the dynamic and uncertain characteristics of the medical diagnosis task, and to re-determine the relationship between subtasks.

Human-computer dialogue model is a medium for interaction and information exchange between doctors and systems, including the interface model and the dialogue control, which shows doctor's decision tasks at the interface in the process of diagnosis, and the doctors determine the way in which tasks are executed.

The design and implementation of the human-computer dialogue model need the support of the rule base and case base with expert knowledge. The rule base stores the experience of doctor's diagnosis, and the case base stores some typical cases in the diagnosis task. According to expert knowledge and Bayesian network, they get the diagnosis results to recommend some of the most likely tasks for the doctor, and meanwhile provide a reference for medical decision-making. Flow diagram of interactive CAD framework is shown in FIGURE 5.

When running system, if we input the currently diagnosed cases, the system will retrieve similar cases in the case database. If there are similar cases, the decision will be provided to the doctor, otherwise Bayesian network model is built according to the rule base, thus providing several possible decisions for doctors. At the same time, the system will continue to collect diagnostic cases into the case database automatically.

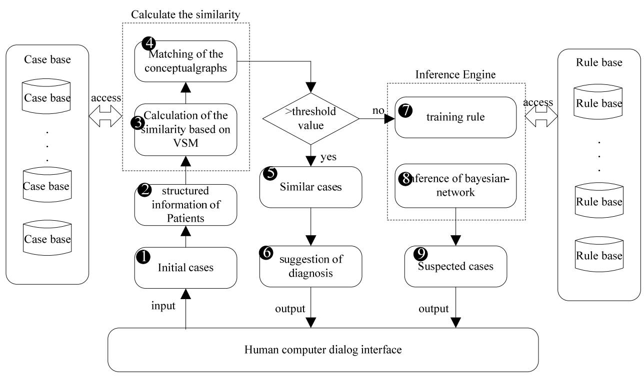

FIGURE 5. **Flowdiagram of interactive CAD framework.**

A. BAYESIAN NETWORK MODEL

The various attributes of the patient characteristics (such as regular smoking, long-term cough, and excessive drinking) constitute a Bayesian network nodes in the collection $X = \{x_1, x_2, \ldots, x_n\}$. The joint probability formula is as follows (see Eq. 1):

$$P(X) = \prod_{i=1}^{n} p(x_i|pa_i) \tag{1}$$

Among them, pa_i is the parent node set of the node x_i. According to the input of the case characteristics, when the probability is greater than the threshold (assumed to be 0.85), it is recommended to diagnosis scheme for doctors and will be presented at the interface. The next task will be performed after the decision.

B. CASE SIMILARITY

Hypothetical case is represented by the vector V_i. Case set V_i consist of m features. Then the case set V is expressed as follows (see Eq. 2):

$$V=\begin{bmatrix} V_1 \\ V_2 \\ \cdots \\ V_i \\ \cdots \\ V_m \end{bmatrix}=\begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1j} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2j} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ v_{i1} & v_{i2} & \cdots & v_{ij} & \cdots & v_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mj} & \cdots & v_{mn} \end{bmatrix} \tag{2}$$

Among them, V_{ij} represents the first j characteristic of the first i case.

The similarity formula of the two cases is as follows (see Eq. 3):

$$Sim(V_i, V_j)=\frac{V_i^T V_j}{||V_i|| \bullet ||V_j||}=\frac{\sum_{k=1}^{n} w_{ik} \bullet w_{jk}}{\sqrt{\sum_{k=1}^{n} w_{ik}^2 \bullet \sum_{k=1}^{n} w_{jk}^2}} \tag{3}$$

Among them, $||V_i||$ and $||V_j||$ are the norms of V_i and V_j respectively, w_{ik} and w_{jk} are the weights of the first k features of V_i and V_j respectively.

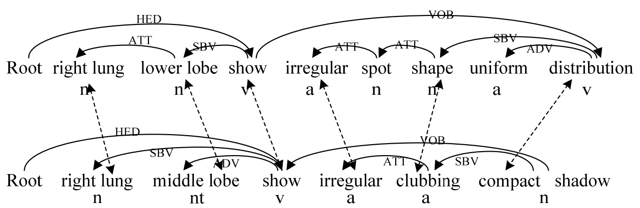

FIGURE 6. Results of syntactic analysis.

Each conceptual graph has only one root node, i.e., node associated with "Root" via "HED" in FIGURE 6. According to the results of syntactic analysis, the corresponding conceptual graphs [21], [22] are established, as shown in FIGURE 7.

Two graphs start to be matched from their root nodes. according to the literature [22], [23], the matching algorithm for the two graphs is as follows (see Eq. 4).

$$sim_g(G_q, G_d)=w(c_q^0, c_d^0)\bullet sim_c(c_q^0, c_d^0)+max\{\sum_{i=1}^{n} w(c_q^i, c_d^i) \bullet sim_r(r_q^i, r_d^i) \bullet [sim_g(G_q^i, G_d^i)]\}$$

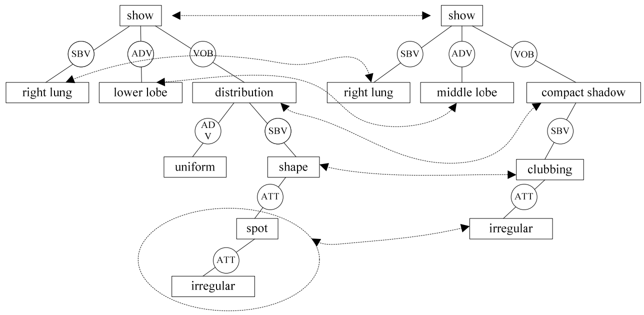

FIGURE 7. Two matching relation of conceptual graphs.

$$w(c_q^0, c_d^0)+\sum_{i=1}^{n} w(c_q^i, c_d^i)=1$$

$$sim_r(r_q, r_d)=\begin{cases} 1 & compatible \\ 0 & incompatible \end{cases} \tag{4}$$

Among them, sim_g is the similarity of the graphs; sim_c is the similarity of concept node; sim_r is the similarity of relationships between two nodes; c_q^0 and c_d^0 are the entrance nodes of the two graphs respectively; $w(c_q^i, c_d^i)$ is the weight of the edge between the first i subtree and the parent node.

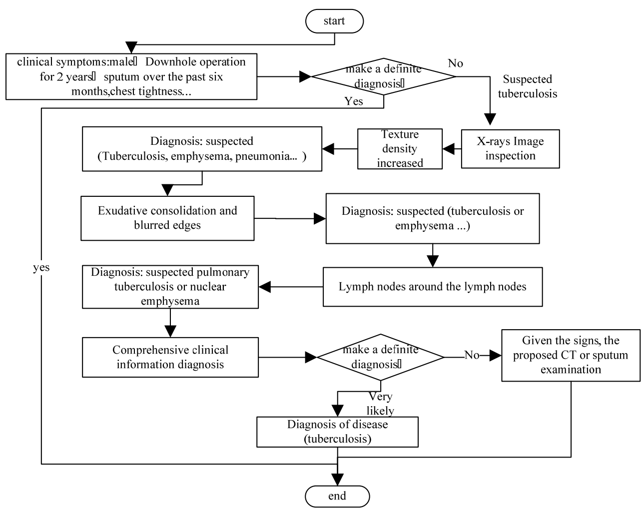

FIGURE 8. Flow chart of diagnostic tasks for pulmonary tuberculosis.

V. CASE STUDY

This paper takes a diagnosis of pulmonary tuberculosis as an example, and analyzes the advantages and disadvantages of CTT and PTT models in the doctors' diagnosis task analysis. A process of diagnosis of pulmonary tuberculosis is shown in FIGURE 8.

The CTT model for diagnosis of pulmonary tuberculosis is shown in FIGURE 9.

In the course of the doctor's diagnosis, different doctors have different diagnoses on the same symptoms, which may cause the uncertainty of the relationship between the sub-tasks. For example, after performing the "clinical diagnosis"

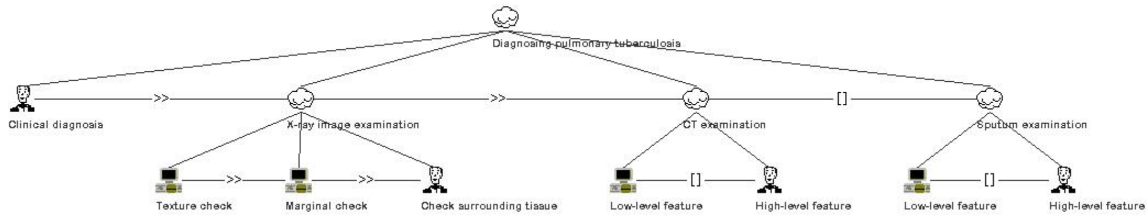

FIGURE 9. **CTT model for diagnosis of pulmonary tuberculosis.**

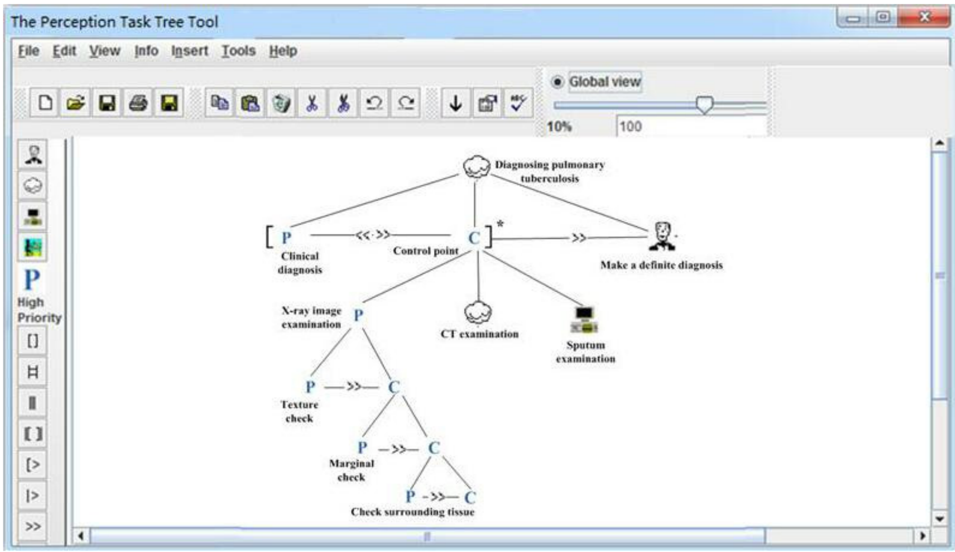

FIGURE 10. **PTT model for diagnosis of pulmonary tuberculosis.**

task, doctors may make corresponding diagnosis respectively based on their own experience knowledge, which leads to the uncertainty of the order of executing tasks. In this case, for the ''X-ray image examination'', ''CT-examination'', and ''Sputum examination'', which one should be performed firstly is not sure. However, when ''clinical diagnosis'' task is completed, ''X-ray image inspection'' task will be performed in FIGURE 9, which is a definite diagnosis process inconsistent with the doctor's diagnosis process in the real world. Task temporal relationships such as the uncertainty are often encountered in the course of the doctors' diagnosis. CTT has a rich representation of temporal relationships, but it can not express the relationship between the uncertainty tasks, which will cause difficulties to design interactive interface.

The PTT model corresponding to the diagnosis of pulmonary tuberculosis is shown in FIGURE 10.

Here the ''texture inspection'', ''edge inspection'' and ''inspection of the surrounding organizations'' are perceived tasks, and the implementation of each subtask is the perception of control process, and the three subtasks can be implemented in any manner. There are uncertain temporal relationships among ''X-ray examination'', ''CT examination'' and ''sputum examination''. Clinical diagnosis is the initial diagnosis of the doctor in the brain (decision). The decision results determine directly what subtask to perform, and this decision is dynamic and is not planned in advance. Different doctors will make different decisions, and the perception task and the control point jointly determine the temporal relationship of the implementation between the subtasks. This is the difference between PTT and the previous opinions of the system modeling tasks.

VI. EXPERIMENTAL ANALYSIS

A. COMPARATIVE ANALYSIS OF TASK MODELS

From the description of above three methods (flowchart, CTT and PTT), it can be seen that the flow chart focuses on the process representation of the task, which is not intuitive. Although the CTT model uses graphical representation symbols, it is more intuitive in expressing ability. However, CTT only describe the deterministic relationship which is static invariant between subtasks. Compared with CTT, PTT has the following advantages: (1) it can support the representation of the uncertainty of task analysis, and when different doctors make different decisions to perform different tasks, it can describe the dynamic nature of the task; (2) it is user-oriented. The user determines autonomously the order of execution of tasks during system execution. Unlike the dynamic task models such as DynaMo-AID and DAMo, which are modeling for the location of the mobile environment, the perceived control theory is not introduced into the task model, thus can not reflect the perception behavior of human brain and the iterative process of the doctor's diagnostic task.

One-way ANOVA test was used to compare the differences among CTT, DynaMo-AID and PTT in terms of usability via questionnaire and experimental evaluation [38], [39]. The evaluationindicators of system usability included ease of learning, operability, and development efficiency were compared. We randomly selected 30 developers (10 developers with less than one year development experience, 10 developers with more than 5 years development experience, and 10 developers with more than 10 years development experience) to model the tuberculosis diagnosis task by using these three task modeling tools, and then scored them according to the above indicators (using a discrete scale from 1 to 10).

The One-way ANOVA test showed some difference with usability among the three models, as shown in TABLE 1. Among them, the independent variables were three models, including three levels, namely PTT, CTT and DynaMo-AID; the dependent variables were the system availability, including three levels, namely ease of learning, operability, development efficiency. From the perspective of ease of learning, there were no significant differences in the three task models (p=0.0968). From the perspective of operability, there were significant differences in the three task models (p=1.0342e-16), and the significant differences were mainly between CTT and PTT (p=8.4570e-12), and between PTT and DynaMo-AID (p=4.7537e-11), but there were no significant differences between CTT and DynaMo-AID (p=0.0503). From the perspective of development efficiency, there were significant differences in the three task models (p=3.2102e-19), and the significant differences were mainly between CTT and DynaMo-AID (p=3.0346e-13), and between PTT and DynaMo-AID (p=9.6577e-16), but there were no significant differences between DynaMo-AID and PTT (p=0.0602).

Overall, the availability of PTT was better than CTT, and the availability of DynaMo-AID was better than CTT. CTT was not good at describing complex and uncertain tasks [9], [10], so the operability and development efficiency score were lower than the PTT; while DynaMo-AID has been improved in terms of dynamic task descriptions [14], [17], so the score of which in development efficiency was close to PTT.

B. COMPARISON OF SEVERAL RETRIEVAL METHODS

The recall rate and precision rate are used to measure the effect of several methods (probabilistic retrieval, cosine-vector, and method of combination of vector and semantic) on case retrieval, and the comparison results of the above methods are shown in FIGURE 11.

FIGURE 11 shows the proposed method is better than the other two kinds of retrieval methods, it uses cosine method to improve the recall rate of case retrieval firstly, then uses semantic retrieval to improve retrieval accuracy for helping doctors to make decisions accurately.

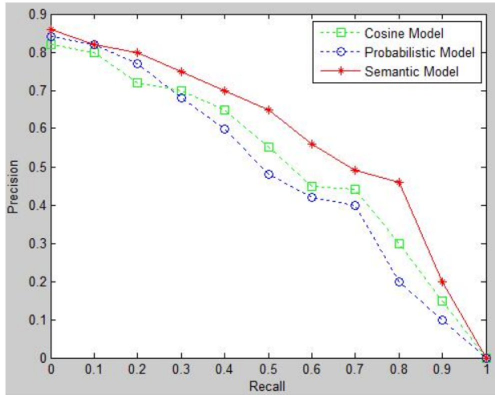

FIGURE 11. Recall and Precision of the case retrieval.

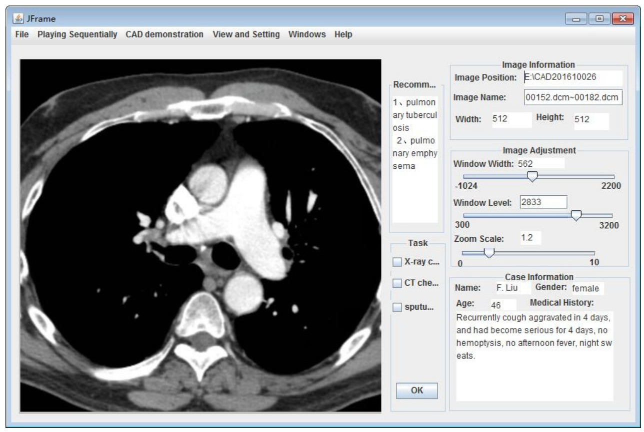

FIGURE 12. Interactive CAD prototype system.

C. SYSTEM EVALUATION

In order to verify the feasibility and effectiveness of the interactive diagnosis system proposed in this paper, based on the PTT model and the interactive CAD framework, this paper implements an interactive CAD system prototype, as shown in FIGURE 12.

FIGURE 12 is a lung diagnosis example of the system. According to the input case, doctors are recommended two diagnostic results (pulmonary tuberculosis and emphysema) and three diagnosis scheme (X ray, CT examination and sputum examination), when the doctor makes one of decisions, the next diagnosis will be carried out based on in-depth diagnostic results until a final diagnosis is made.

The difference between the existing automated CAD system and the interactive CAD system was that the latter provided the appropriate locating and inspecting tools to assist the doctor to diagnose diseases, thus improved the interaction and diagnostic efficiency by calculating the current lesion with the probability of a certain disease, and improved the accuracy of the diagnosisespecially for inexperienced physicians. The former diagnosed lesions rely solely on the

TABLE 1. One-Way ANOVA test analysis of system availability.

Model / Indicators	PTT		CTT		DynaMo-AID		P-value
	Mean value	Standard deviation	Mean value	Standard deviation	Mean value	Standard deviation	
Ease of learning	8.5600	0.3539	8.4533	0.4652	8.3367	0.3557	0.0968
Operability	8.7900	0.4037	7.8233	0.3839	8.1133	0.2688	1.0342e-16
Developmenteff iciency	8.6100	0.3680	7.5533	0.3794	8.4333	0.3457	3.2102e-19
Overall usability	25.9600	1.1256	23.8300	1.2285	24.8833	0.9702	--

TABLE 2. The weight score of system performance evaluation comprehensive.

Evaluation index / Significance index	Very important (0.9)	Important(0.75)	General (0.6)	Unimportant (0.3)	Very insignificant (0.1)
Availability	8	12	7	2	1
Diagnosis efficiency	12	16	2	0	0
Accuracy	22	8	0	0	0
Correctness of decision	18	12	0	0	0

TABLE 3. Satisfaction score of the existing system.

Evaluation index / Satisfaction index	Very Satisfying	Satisfying	Ordinary	Unsatisfactory	Not at all satisying
Usability	0	8	12	7	3
Diagnosis efficiency	0	6	12	9	3
Accuracy	0	6	15	6	3
Correctness of decision	0	9	12	7	2

low-level features, such as texture features, the size of the lesion to make a judgment, lacking of comprehensive diagnoses and doctors' decisions, and its accuracy rate did not meet the diagnostic requirements. At present, the manual diagnosis system, was used to diagnose foci by doctors via switching HIS system and PACS system, which did not combine the two systems, the diagnostic efficiency was relatively low.

In order to evaluate the performance of the system, we selected 30 doctors (14 doctors were between 25 and 35 years old; 8 doctors were between 36 and 45 years old; 8 doctors were over 45 years old). The foci were diagnosed respectively by the existing system and the CAD system in this paper, and the two systems were evaluated comprehensively from the system availability, diagnosis efficiency of each lesion, accuracy rate of diagnosis and correct rate of decision-making. Among them, the evaluation of system availability included learning time, subjective satisfaction and operability.

The overall performance evaluation scale of the system also has 5 grades: Very satisfying, Satisfying, General and Unsatisfactory and Not at all satisfying. In order to evaluate system performance objectively, the weight of each index is determined by the scoring of each doctor. The weight analysis of the system performance evaluation comprehensive is shown in TABLE 2.

Then let each doctor use the two systems to diagnose a series of cases, and score each indicator respectively. The satisfaction scores of the two systems are shown in TABLE 3 and TABLE 4.

According to the fuzzy comprehensive evaluation method [34], [35], the weight and satisfaction grade membership matrixes of comprehensive evaluation of the systems are established, as shown in FIGURE 13.

Weight evaluation vector $W_{index} = R_{weight} \bullet W_s = R_{weight} \bullet\ (0.9,\ 0.75,\ 0.6,\ 0.3,\ 0.1)' = (0.7044,\ 0.8100,\ 0.8595,\ 0.8400)$, After normalization $W_{index} = (0.3915,\ 0.4502,\ 0.4447,\ 0.4778, 0.4669)$. Then the comprehensive rating membership degree of the existing system $S_{existing} = R'_{existing} \bullet W_{index} = (0.0450,\ 0.5640,\ 0.9461,\ 0.4740,\ 0.1627)$, normalized matrix $S_{existing}$ = (0.0205,0.2574,0.4316, 0.2162,0.0742), the comprehensive score is 3.0662. Similarly,the comprehensive rating membership degree of the interactive system $S_{interactive} = R'_{interactive} \rangle W_{index} = (1.1109,\ 0.9758,\ 0.1315,\ 0.0129,\ 0)$, normalized matrix $S_{interactive} = (0.4979,\ 0.4373,\ 0.0589,\ 0.0058,\ 0)$. Finally, the

TABLE 4. Satisfaction score of the interactive CAD system.

Evaluation index \ Satisfaction index	Very Satisfying	Satisfying	Ordinary	Unsatisfactory	Not at all satisying
Usability	9	18	2	1	0
Diagnosis efficiency	6	21	3	0	0
Accuracy	24	5	1	0	0
Correctness of decision	22	8	0	0	0

$$W=\begin{bmatrix} 0.27 & 0.4 & 0.23 & 0.067 & 0.033 \\ 0.4 & 0.533 & 0.067 & 0 & 0 \\ 0.73 & 0.27 & 0 & 0 & 0 \\ 0.6 & 0.4 & 0 & 0 & 0 \end{bmatrix}$$

(a)

$$R_{existing}=\begin{bmatrix} 0 & 0.267 & 0.3 & 0.233 & 0.1 \\ 0 & 0.2 & 0.4 & 0.3 & 0.1 \\ 0 & 0.2 & 0.5 & 0.2 & 0.1 \\ 0 & 0.3 & 0.4 & 0.233 & 0.067 \end{bmatrix}$$

(b)

$$R_{interactive}=\begin{bmatrix} 0.3 & 0.6 & 0.067 & 0.033 & 0 \\ 0.2 & 0.7 & 0.1 & 0 & 0 \\ 0.8 & 0.167 & 0.033 & 0 & 0 \\ 0.733 & 0.267 & 0 & 0 & 0 \end{bmatrix}$$

(c)

FIGURE 13. The weight and satisfaction grade membership matrixes of comprehensive evaluation of the system.

comprehensive score is 1.5726. It can be seen that the overall evaluation results of the existing system and the interactive CAD system by the doctors are ''General'' and ''Satisfying'' respectively.

It is not difficult to see from that, the comprehensive performance of the interactive CAD system is obviously better than the current CAD system. The reason is that not only the availability of interactive CAD system is better than the existing system for doctors to recommend an effective diagnostic program to improve the average correct rate of diagnosis of lesions, but also it reduces the time of diagnosis of lesions.

VII. CONCLUSION AND NEXT WORK

To solve the problems that the existing CAD system is not consistent with the doctor's diagnosis process, and the accuracy rate of diagnosis is not up to the doctor's request, this paper presents an interactive CAD system framework, combined HTA, CTT and PCT features with the DynaMo-AID dynamic characteristics, and puts forward the PTT model which is suitable for the doctor's diagnosis task, in order to solve the problem of insufficient description of the uncertain task in the diagnosis task, and provide a reference for future uncertainty analysis task. Based on the interactive CAD framework, the prototype system of interactive CAD system is realized by the Bayesian network model reasoning and case similarity calculation, and provide effective support for physician assisted decision making.

In the following work, we will design and implement a PTT task modeling tool to facilitate the task analysis; and collect more case information to enrich the case bases and rule bases, and formalize the subtasks, and build a more perfect Bayesian network model, and explore a more reasonable human-computer dialogue model to improve the interactive CAD system.

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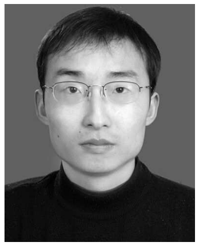

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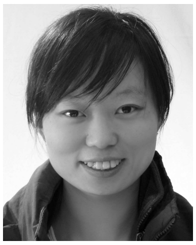

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