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The Personalized Traditional Medicine Recommendation System Using Ontology and Rule Inference Approach

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Abstract—**The purpose of this research was to solve the complication associated with the recommendation of traditional herbal medicines, concerning the fact that an appropriate use of traditional herbal medicines entails contemplation of personal health information that include age, body temperature, pregnancy, lactation, chronic diseases, and medicines taken on a regular basis. Likewise, some traditional herbal medicines cannot be taken by patients with certain health conditions. Accordingly, this research proposed a system that provides recommendations of traditional herbal medicines according to each patient's health information by applying an ontology-based knowledge representation technique that employs Web Ontology Language (OWL) to process and describe data in the ontology. Rules were expressed in the form of a rule language so as to enable the computer to infer and provide recommendations of traditional herbal medicines and their contraindications in a similar manner to a medical specialist. To test the efficiency of the proposed system in solving the complication and providing personalized recommendations, an experiment was conducted based on three scenarios: (1) the case of more than one diseases with different personal health information; (2) the case of more than one diseases with specified personal health information; and (3) the case of same disease with different personal health information. Upon assessment of the system efficiency by a medical specialist, the system was found to be capable of providing personalized recommendations of traditional herbal medicines and their contraindications in an efficient manner.**

Keywords-ontology-based; recommendation system; personalized recommendation; traditional herbal medicines

I. INTRODUCTION

Traditional herbal medicines are natural products with similar effectiveness of treatment to some conventional medicines but with less side effects on account of the fact that conventional medicines are predominantly developed from chemical substances. In addition, traditional herbal medicines are considerably cheap and widely available in the market. Nonetheless, there are various limitations of traditional herbal medicines; some traditional herbal medicines cannot be used in patients with certain medical conditions or complications, or in pregnant or lactation patients. With respect to the foregoing limitations, it is undoubtedly complicated to recommend traditional herbal medicines that are appropriate to each patient's health condition.

Accordingly, it is expedient to develop a system that provides personalized recommendations of traditional herbal medicines to address the abovementioned limitations. Despite the fact that various database management systems have been developed to facilitate the search of data concerning traditional herbal medicines, these systems do not address the limitations of traditional herbal medicine recommendations. Conversely, these systems were developed to merely search data from the relationship field in a table, and are therefore limited by a lack of functions to infer implicit knowledge from data relationships to create new knowledge.

Indeed, many previous studies have applied an ontology-based technology to enhance performance in healthcare and life sciences, such as an ontology-driven differential diagnosis (ODDIN) [1] and a decision support system for monitoring blood sugar levels of diabetic patients who require surgical procedures [2]. Similarly, an ontology-based technology has been adopted to provide recommendations for both conventional medicines and traditional herbal medicines. For instance, Chen et al. [3] developed an ontology using Semantic Web Rule Language (SWRL) to recommend medicines to diabetic patients, while Doulaverakis et al. [4] proposed an ontology-based drug recommendation system, namely GalenOWL. Kato et al. [5] proposed an ontology for treatment of diseases based on the Thai traditional medicine. Nonetheless, it is apparent that none of the previous studies developed a system to provide personalized recommendations of traditional herbal medicines that correspond to each patient's health condition.

In that regard, this research proposed an approach to solve the complication associated with the recommendation of traditional herbal medicines by presenting a system that provides recommendations of traditional herbal medicines based on each patient's health condition. In developing the foregoing system, an ontology-based knowledge representation technique was employed in conjunction with Web Ontology Language (OWL) to describe data in the ontology. Furthermore, rules were expressed in the form of a rule language to enable the computer to infer and provide recommendations of traditional herbal medicines, as well as their contraindications, that are consistent with the recommendations of a medical specialist.

II. LITERATURE REVIEW

A. Ontology and Semantic Web Language

Semantic Web technologies enhance the capability of current web technologies, hence enabling computers or software agents to understand the semantically content of web resources in conformity with human understanding and ultimately become machine-understandable. Ontology is an essential component used to describe the scope of any subject area that is of our interest, as well as representing the scope of data in a standardized form. Regarding the Semantic Web Language, OWL is considered to be the language that is most widely used in representing and defining data in an ontology [6]. OWL can further be used to determine relationships and properties of data, thus allowing an inference engine to deduce data and discern relationships at a deeper level. A Semantic Web Rule Language (SWRL) is a tool that can be used to construct additional rules to enhance the intelligence of data inference.

Upon the study of related theories, this research constructed the traditional herbal medicine ontology by using OWL to describe the scope of knowledge and the relationships of data on traditional herbal medicines. Meanwhile, SWRL was employed to construct rules so as to enable the computer to infer and provide recommendations of traditional herbal medicines that are consistent with each patient's health condition.

III. RELATED WORK

For decades, several researchers have attempted to develop technologies to address the failures concerning recommending issues. Several techniques have been developed to improve performance.

A. Data Mining Techniques for Medicine Recommendation and Diagnosis

Syed-Abdul et al. [7] employed the association rule mining technique to identify the relationship between diseases and medicines that are correlated with disease names. The researchers analyzed the prescription records obtained from a hospital and presented a concept that displays a list of most relevant medicines by ranking the medicines recommended by a system called "Mean Prescription Rank (MPR)". Although the proposed concept was able to reduce prescription errors, there were still some limitations with respect to an appropriate selection of relationships. Another study conducted by Y. Zhang et al. [8] proposed a cloud-based medicine recommendation system (COMER) to recommend medicines to patients who wish to purchase their medicines through e-commerce stores. The K-means clustering technique was adopted to classify medicines based on their treatment properties, and the system was designed using collaborative filtering and tensor decomposition techniques. The proposed system was able to provide convenience to users by recommending a list of medicines that correspond to each user's symptoms. Alternatively, Bao and Jiang [9] adopted data mining techniques to design and develop a medicine recommendation system using diagnostic records. Information employed in data processing consisted of gender, age, blood pressure level, cholesterol level, Na level, and K level. Moreover, the support vector machine (SVM) algorithm, the BP neural network algorithm, and the ID3 decision tree algorithm were compared in terms of efficiency. According to the results, the SVM algorithm was able to provide medicine recommendations with the accuracy rate of 95% and was found to be the least time-consuming with regard to the processing time. Nevertheless, this research had several limitations such as the lack of factors employed in the analysis of medicine recommendations. Chen et al. [10] presented a disease diagnosis and treatment recommendation system (DDTRS) by classifying disease symptoms using the density peak clustering algorithm (DPCA). The association rule mining technique was employed to determine the disease-diagnosis and the disease-treatment association rules. According to the results, the system was able to serve as a tool to aid physicians who lack experience in making diagnostic and treatment decisions.

Upon examination of previous studies related to the application of data mining techniques in medicine and diagnosis recommendations, it is evident that there are some limitations of data regarding medicine recommendations and contraindications, as well as relevant factors pertaining to each patient's personal health information.

B. Ontology-Based Techniques for Medicine Recommendation and Diagnosis

An ontology-based technique is one of the semantic-based recommendation approaches. Many researchers have expressed interest in applying ontology-based techniques to develop a recommendation system for medical practices, such as medicine and diagnosis recommendations. Doulaverakis et al. [4] proposed a medicine recommendation system called "GalenOWL", which is capable of offering medicine recommendations and contraindications to patients. The system was designed by translating medical information and terminology into ontological terms and creating rules for recommendations of medicines and their contraindications. However, the foregoing system still lacked an appropriate assessment on the efficiency and accuracy of the system. Another study conducted by Chen et al. [3] presented a medicine recommendation system for diabetic patients through the application of an ontology-based technique. Data were analyzed based on the American Association of Clinical Endocrinologists Medical Guidelines for Clinical Practice for the Management of Diabetes Mellitus (AACEMG) to construct ontologies and rules for medicine recommendation. The system efficiency was tested by experimenting on 20 datasets of diabetic patients. The results suggested that the system had a high rate of accuracy and could be used as a tool to support physicians in making prescription decisions for diabetic patients.

Upon examination of previous studies, it is evident that there has not yet been any development of a personalized recommendation system for herbal medicines. Thus, the researcher believed that it is expedient to utilize the advantages of ontology-based techniques to develop a traditional herbal medicine recommendation system that can solve the complication in recommending traditional herbal medicines that are appropriate to each patient's health condition.

IV. Propose Approach

A. Conceptual Framework

There are three scenarios that contribute to the differences in the recommendation of traditional herbal medicines between each patient, consisting of:

1) The case where patients have similar demographic characteristics such as age, gender, pregnancy status, and lactation status but different illnesses or chronic diseases. For example, Patient 01 is a 56-year-old male patient suffering from flatulence and diagnosed with biliary atresia, while Patient 02 is a 60-year-old male patient suffering from flatulence in concurrence with constipation but has no other chronic diseases. In such case, the patients should receive different recommendations for traditional herbal medicines and contraindications.

2) The case where patients have different demographic characteristics but with one identical illness. For instance, Patient 01 is a 9-year-old child suffering from flatulence and Patient 02 is a 35-year-old pregnant woman suffering from flatulence. Although both patients suffer from the same illness, they should receive different recommendations for traditional herbal medicines and contraindications.

3) The case where patients have different demographic characteristics, as well as different illnesses such as chronic diseases and different medications taken on a regular basis. Accordingly, patients should receive different recommendations for traditional herbal medicines and contraindications.

Based on the three foregoing scenarios, it is evident that the recommendation of traditional herbal medicines that are appropriate to each person is complicated.

To solve the complication in recommending traditional herbal medicines that are appropriate to each patient's health condition, the conceptual framework for development of a traditional herbal medicine recommendation system was proposed to address the aforementioned issue. The conceptual framework of this research consists of two processes, namely ontology modeling and recommendation rule construction, as illustrated in Fig. 1.

After inputting relevant health and personal information of each patient, the system will map the data based on the ontological structures that have been designed and developed in the ontology modeling process. After that, the data will be processed through the rules that have been constructed, and the system will recommend traditional herbal medicines that correspond to each patient's information.

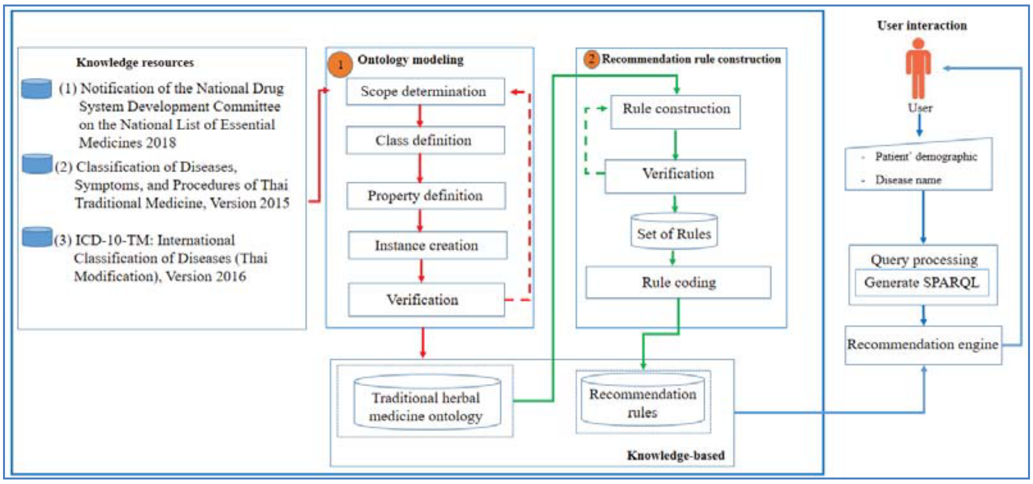

Figure 1. Recommendation system framework.

B. Ontology Modeling

This process has the objective to construct the traditional herbal medicine ontology that encompasses knowledge pertaining to the use of traditional herbal medicines. To achieve the said objective, three knowledge resources were determined: (1) Notification of the National Drug System Development Committee on the National List of Essential Medicines 2018 [11]; (2) Classification of Diseases, Symptoms, and Procedures of Thai Traditional Medicine, Version 2015 [12]; and (3) ICD-10-TM: International Classification of Diseases (Thai Modification), Version 2016 [13]. The development of ontology consists of five processes, as follows:

1) Scope determination

This process aims to determine the scope and objectives of the development of traditional herbal medicine ontology to be used as a knowledge base for the proposed system. The system must be able to provide answers to the questions in five aspects: (1) What traditional herbal medicines are in the national list of essential medicines? (2) What diseases associated with the Thai traditional medicine can be treated with traditional herbal medicines? (3) What diseases associated with the Thai traditional medicine are prohibited from traditional herbal medicine treatment? (4) What conventional medicines cannot be used in conjunction with traditional herbal medicines? (5) What traditional herbal medicines will be recommended to patients? This process comprises three steps:

a) Determining the names and regimens of traditional herbal medicines

This step involves analyzing information about traditional herbal medicines available in knowledge resources (1) to obtain: (1) Recommendations of traditional herbal medicines, specifically their scope of treatment, and (2) Contraindications of traditional herbal medicines that may severely affect the health of users. These include: Age; Lactation status; Pregnancy status; Fever symptoms; Diseases that are prohibited from using traditional herbal medicines as treatment; and Medicines (both conventional medicines and traditional herbal medicines) that cannot be used in conjunction with traditional herbal medicines.

b) Determining the ICD-10 code

The results obtained from the previous step were used to assign ICD-10 codes to a list of diseases by:

- Assigning ICD-10 codes to the diseases associated with the Thai traditional medicine that were obtained from knowledge resources (1) with reference to the information from knowledge resources (2).
- Assigning ICD-10 codes to the diseases associated with the Thai traditional medicine that were obtained from knowledge resources (1) with reference to the information from knowledge resources (3).

c) Designing the ICD-10 code structure

To ensure that the constructed rules can search for diseases associated with both the Thai traditional medicine and the conventional medicine, the ICD-10 code structure was designed to integrate the structure of knowledge resources (2) into the primary ICD-10 code structure in knowledge resources (3).

2) Class definition

This process aims to define various classes in the traditional herbal medicine ontology according to the specified scope, which consists of two steps as follows:

a) Classifying ontological terms or elements into nouns and verbs

- Nouns include the national list of essential medicines, traditional herbal medicines, conventional medicines, diseases associated with the Thai traditional medicine, diseases associated with the conventional medicine, and ICD-10 codes.
- Verbs include treatment properties, symptoms, restrictions of use in pregnant patients, and restrictions of use in elderly people.

b) Determining classes that are related to the work system

This step involves selecting the nouns to act as a class and clustering similar instances or members into the same class. Three classes were determined in this step:

- The “ICD10” class, which comprises data relating to the ICD-10 codes and symptoms, with a structure based on knowledge resources (2) and (3).
- The “Medicine” class, which stores data on traditional herbal medicines and conventional medicines. Hence, this class consists of two sub-classes, namely the “TraditionalMedicine” class and the “ConventionalMedicine”, with a structure based on knowledge resources (1).
- The “Patient” class that stores data on the health conditions of traditional herbal medicine users.

3) Property definition

This process defines and assigns a property to each class that was determined from the previous stage. The process includes:

a) Constructing the class property

This step encompasses defining the verbs from (2) in the “Class definition” stage as the property of each class. Table 1: Construction of the class property.

TABLE I. CONSTRUCTION OF THE CLASS PROPERTY

Question	Class	Property	Class/ data type
(1) What traditional herbal medicines are in the national list of essential medicines?	Medicine	hasMedicineName	Literal
(2) What diseases associated with the Thai traditional medicine can be treated with traditional herbal medicines?	ICD 10	hasDiseaseName	Literal
	ICD 10	treatDiseaseBy	Medicine
	Medicine	treatDisease	ICD 10
(3) What diseases associated with the Thai traditional medicine are prohibited from traditional herbal medicine treatment?	ICD 10	limitDiseaseByMedicine	Medicine
	Medicine	limitToDisease	ICD 10
(4) What conventional medicines cannot be used in conjunction with traditional herbal medicines?	Medicine	limitToMedicine	Medicine
	Medicine	hasMedicineName	Literal

b) Classifying properties

In an ontology, a property can be classified into two types, namely ObjectProperty and DatatypeProperty. This step has the objective to classify each property based on the type of data it stores.

ObjectProperty can be determined by defining the range of property (that is assigned to a class) as ObjectProperty. From Table 1, the “treatDiseaseBy”, “treatDisease”, “limitDiseaseByMedicine”, “limitToDisease”, and "limitToMedicine" properties were defined as ObjectProperty since their ranges were assigned to a class.

DatatypeProperty can be determined by defining the range of property that is assigned to numerical data, such as literal, integer, and float, but not the class name. Hence, from Table 1, the "hasMedicineName", "hasDiseaseName", and "hasMedicineName" properties were defined as DatatypeProperty.

Upon classification of properties, a domain was assigned to each property by defining the classes in the second column of Table 1 as the domain of property.

c) Determining property restrictions

After classifying the properties and assigning a domain and range to each property, the next step involves determining the restrictions and constraints for each property. This can be performed by:

Determining the number of properties (property cardinality) by using the <owl:cardinality> constraint. For instance, the data on the age of each person should have only one value. Hence, the "hasAge" property must be able to collect only one value relating to age. The <owl:cardinality> constraint was therefore used to limit the number of "hasAge" properties.

Using the <owl:hasValue> constraint to determine the scope of the "hasPregnantStatus" property and the "hasLactationStatus" property. To use both properties, the "hasGenderGroup" property of the "Patient" class instance must be equal to "Female".

Determining a constraint that allows an inference engine to discern the relationship between the subject (instance) and the object of a property. For example, the symmetric property can be assigned to the "limitToDisease" property, which can be expressed in a triple form as the figure 2:

(limitToDisease, rdf:type, SymmetricProperty)
(Medicine, limitToDisease, Medicine)
(YA-KA-MIN-CHAN, limitToDisease, Aspirin)

Figure 2. Determination of symmetric property in a triple form.

According to the above constructions, the inference engine would not only infer that there is a limitation on the medicine when used in conjunction with aspirin, but it would also discern the relationship that aspirin cannot be used in combination with turmeric medicine.

4) Instance construction

The results from Scope Determination, Class Definition, and Property Definition can be used to determine the structure of the traditional herbal medicine ontology at the schema level. This step focuses on the instance level to construct instances in the ontology, whereby all class attributes will be transferred to the class instance, which enables the specified properties to be used. The process of instance construction can be explained as follows:

a) Constructing instances from nouns

Examples of nouns include ginger medicine and turmeric medicine (relating to herbal medicine information) and flatulence (relating to the name of the disease associated with the Thai traditional medicine). Since the "TraditionalHerbalMedicine" class was constructed from the "Class Definition" stage to store data on traditional herbal medicines at the schema level, the "YA-KING" (ginger medicine) instance and the "YA-KA-MIN-CHAN" (turmeric medicine) instance were thus constructed to be in the "TraditionalMedicine" class. Meanwhile, the "U66_80_Normal_Flatulence" instance was constructed to be in the "ICD10" class at the instance level.

b) Determining properties that were transferred from a class to an instance.

For example, determining the "hasMedicineName" property and the "treatDisease" property in the "Medicine" class, and the "hasDiseaseName" property in the "ICD10" class.

5) Verification

Data concerning ontological structures and instances were verified with information in knowledge resources (1), knowledge resources (2), and knowledge resources (3) to ensure accuracy. Any necessary modifications were performed, and an interview was conducted with a specialist in the Thai traditional medicine to confirm the accuracy of data. The next process involves constructing rules for the traditional herbal medicine recommendation system.

B. Recommendation Rule Construction

The following process is highly important, owing to the fact that it is concerned with the construction of rules that enable the computer to process data and recommend traditional herbal medicines that correspond to the health condition of each patient. This process consists of two steps:

1) Rule construction and verification

a) Rule construction for patients with diseases that are consistent with the properties of herbal medicines

The objective of recommendation rule construction was to enable the computer to process data and recommend traditional herbal medicines that are aligned with the recommendation of a medical specialist. Factors that were taken into account for the recommendation of traditional herbal medicines include:

Data on health conditions (diseases), as illustrated in the relationship between the "Patient" class and the "ICD10" class => sufferDisease(Patient, ICD 10).

Traditional herbal medicines that can treat diseases, as illustrated in the relationship between the "Medicine" class and the "ICD10" class => treatDisease(Medicine, ICD 10).

Traditional herbal medicines that should be recommended to patients, as illustrated in the relationship between the "Medicine" class and the "Patient" class => recommendTo(Medicine, Patient) and recommendBy(Patient, Medicine).

Accordingly, the "sufferDisease" property and the "treatDisease" property were defined as the input, and the "recommendTo" property and the "recommendBy" property were defined as the output from the system inference.

The system would take the results from this step to provide recommendations of traditional herbal medicines by mapping the name of the disease that can be treated with traditional herbal medicines to the name of the disease suffered by the patient. Nonetheless, this does not solve the complication associated with the recommendation of traditional herbal medicines nor provide personalized recommendations of traditional herbal medicines to patients. To address these concerns, rules were constructed for the contraindications of traditional herbal medicines that correspond to each patient's health condition.

According to the results from the "Scope Determination" stage, the contraindications of traditional herbal medicines consist of six aspects. Hence, the rules for contraindications of traditional herbal medicines were constructed to embrace all six aspects. The steps are as follows:

- Defining properties relating to the benefits and limitations of traditional herbal medicines, as well as properties relating to health conditions and personal health information of each patient, as the input for rule inference.
- Defining properties pertaining to the contraindications of traditional herbal medicines (based on each patient's health condition) as the output from rule inference.

The next step involves combining data from the two previous steps to construct rules, as detailed below.

b) Constructing a contraindication rule for patients who are outside the age eligibility criteria for traditional herbal medicines.

Concerning the fact that age restrictions do not specify the exact age but merely describe the age characteristics, the age range of traditional herbal medicine users was determined as follows:

- 0 – 1 years is defined as "Newborn"
- 2 – 6 years is defined as "Small_Child"
- 7 – 12 years is defined as "Child"
- 13 – 60 years is defined as "Adult"
- 61 years and above is defined as "Elderly"

Constructing a rule for inferring age values in the "hasAge" property to be in a descriptive term according to the "hasAgeLevel" property defined above.

Comparing the "limitToAgeLevel" property range of the "Medicine" class instance with the "hasAgeLevel" property range of the "Patient" class instance to determine whether they are consistent. If the property ranges are consistent, the system would infer the domain value of the "contraindicationMedicineInPatientWithAgeLevel" property to be equal to the "Medicine" class instance and define the range as the "Patient" class instance.

c) Constructing a contraindication rule for pregnant patients

Comparing the "hasPregnantStatus" property range of the "Patient" class instance with the "limitToPregnantProfile" property range of the "Medicine" class instance to determine whether they are consistent. If the property ranges are consistent, the system would infer the domain value of the "contraindicationMedicineInPregnantPatient" property to be equal to the "Medicine" class instance and define the range as the "Patient" class instance.

d) Constructing a contraindication rule for lactation patients

Comparing the "hasLactationStatus" property range of the "Patient" class instance with the "limitToPregnantProfile" property range of the "Medicine" class instance to determine whether they are consistent. If the property ranges are consistent, the system would infer the domain value of the "contraindicationMedicineInLactationPatient" property to be equal to the "Medicine" class instance and define the range as the "Patient" class instance.

e) Constructing a contraindication rule for patients with fever symptoms

Since the contraindications of herbal medicines for patients with fever symptoms are described in statements, such as "Do not use in patients with fever symptoms", the range of temperature was determined in Celsius to differentiate between patients with fever symptoms and patients without fever symptoms, as follows:

- Body temperature of 35.0 – 37.4 is defined as "Normal Temperature"
- Body temperature of 37.5 – 40.0 is defined as "High Temperature"

Constructing a rule for inferring body temperatures that are in decimal numbers to bear the value of the range of body temperatures and determining the value to be equal to the range of the "hasTemperatureLevel" property.

Comparing the "limitToTemperatureLevel" property range of the "Medicine" class instance with the "hasTemperatureLevel" property range of the "Patient" class instance to determine whether they are consistent. If the property ranges are consistent, the system would infer the domain value of the "contraindicationMedicineInPatientWithHighTemperature" property to be equal to the "Medicine" class instance and define the range as the "Patient" class instance.

f) Constructing a contraindication rule for patients with diseases that are prohibited from herbal medicine treatment

Comparing the "sufferComorbidity" property range of the "Patient" class instance with the "limitToDisease" property range of the "Medicine" class instance to determine whether they are consistent. If the property ranges are consistent, the system would infer the domain value of the "contraindicationMedicineInPatientWithDisease" property to be equal to the "Medicine" class instance and define the range as the "Patient" class instance.

g) Constructing a contraindication rule for patients who take medicines that cannot be used in conjunction with herbal medicines

Comparing the "takeMedicine" property range of the "Patient" class instance with the "limitToMedicine" property range of the "Medicine" class instance to determine whether they are consistent. If the property ranges are consistent, the system would infer the domain value of the "contraindicationMedicineInLimitMedicine" property to be equal to the “Medicine” class instance and define the range as the “Patient” class instance.

2) Rule coding

This step consists of two main internal processes: (1) Expressing the rules constructed from the previous stage in the form of SWRL and (2) Inferring rules for recommendation of herbal medicines according to the rules constructed. Table 2 demonstrates 14 rules for recommendation of traditional herbal medicines that correspond to each patient’s health condition, which were constructed from the “Rule Construction and Verification” stage.

TABLE II. RULES FOR PERSONALIZED RECOMMENDATION OF TRADITIONAL HERBAL MEDICINE

No.	SWRL syntax
1	hm:treatDisease(?Medicine, Disease) ^ hm:sufferDisease(?Patient, ?Disease) -> hm:recommendTo(?Medicine, ?Patient)
2	hm:hasAge(?P, ?Age) ^ swrlb:greaterThanOrEqual(?Age, 0) ^ swrlb:lessThanOrEqual(?Age, 1) -> hm:hasAgeLevel(?P, "New_Born")
3	hm:hasAge(?P, ?Age) ^ swrlb:greaterThanOrEqual(?Age, 2) ^ swrlb:lessThanOrEqual(?Age, 6) -> hm:hasAgeLevel(?P, "Small_Child”)
4	hm:hasAge(?P, ?Age) ^ swrlb:greaterThanOrEqual(?Age, 7) ^ swrlb:lessThanOrEqual(?Age, 12) -> hm:hasAgeLevel(?P, "Child”)
5	hm:hasAge(?P, ?Age) ^ swrlb:greaterThanOrEqual(?Age, 13) ^ swrlb:lessThanOrEqual(?Age, 60) -> hm:hasAgeLevel(?P, "Adult")
6	hm:hasAge(?P, ?Age) ^ swrlb:greaterThanOrEqual(?Age, 61) ^ swrlb:lessThanOrEqual(?Age, 100) -> hm:hasAgeLevel(?P, " Elderly ")
7	hm:treatDisease(?Medicine, ?Disease) ^ hm:limitToAgeLevel(?Medicine, ?LimitAgeLevel) ^ hm:sufferDisease(?Patient, ?Disease) ^ hm:hasAgeLevel(?Patient, ?AgeLevel) ^ swrlb:equal(?AgeLevel,?LimitAgeLevel)-> hm:contraindicationMedicineInPatientWithAgeLevel(?Medicine, ?Patient)
8	hm:treatmentDisease(?Medicine, ?Disease) ^ hm:limitToPregnantProfile(?Medicine, "Pregnancy") ^ hm:sufferDisease(?Patient, ?Disease) ^ hm:hasGenderGroup(?Patient, "Female") ^ hm:hasPregnantStatus(?Patient, "Pregnancy") -> hm:contraindicationMedicineInPregnantPatient(?Medicine, ?Patient)
9	hm:treatmentDisease(?Medicine, ?Disease) ^ hm:limitToPregnantProfile(?Medicine, "Lactation") ^ hm:sufferDisease(?Patient, ?Disease) ^ hm:hasGenderGroup(?Patient, "Female") ^ hm:hasLactationStatus(?Patient, "Lactation") -> hm:contraindicationMedicineInLactationPatient(?Medicine, ?Patient)
10	hm:hasTemperature(?Patient, ?Temperature) ^ swrlb:greaterThanOrEqual(?Temperature, 35.0) ^ swrlb:lessThanOrEqual(?Temperature, 37.4) -> hm:hasTemperatureLevel(?Patient, "NormalTemperature")
11	hm:hasTemperature(?Patient, ?Temperature) ^ swrlb:greaterThanOrEqual(?Temperature, 37.5) ^ swrlb:lessThanOrEqual(?Temperature, 40) -> hm:hasTemperatureLevel(?Patient, "HighTemperature")
12	hm:treatDisease(?Medicine, ?Disease) ^ hm:limitToTemperatureLevel(?Medicine, "HighTemperature") ^ hm:sufferDisease(?Patient, ?Disease) ^ hm:hasTemperatureLevel(?Patient, "HighTemperature") -> hm:contraindicationMedicineInPatientWithHighTemperature(?Medicine, ?Patient)
13	hm:limitToDisease(?Medicine, ?LimitDisease) ^ hm:treatDisease(?Medicine, ?Disease) ^ hm:sufferDisease(?Patient, ?Disease) ^ hm:sufferComorbidityDisease(?Patient, ?LimitDisease) -> hm:contraindicationMedicineInPatientWithTheDisease(?Medicine, ?Patient)
14	hm:limitToMedicine(?Medicine, ?LimitMedicine) ^ hm:treattDisease(?Medicine, ?Disease) ^ hm:sufferDisease(?Patient, ?Disease) ^ hm:takeMedicine(?Patient, ?LimitMedicine) -> hm:contraindicationMedicineInLimitMedicine(?Medicine, ?Patient)

V. EXPERIMENT AND RESULTS

Concerning the complication associated with the recommendation of traditional herbal medicines that are appropriate to the personal health information of each patient, this research proposed a traditional herbal medicine recommendation system by applying an ontology-based technique and rule inference. The research had the objectives to: (1) assess the efficiency of the system in solving the complication of traditional herbal medicine recommendations and (2) assess the efficiency of the system in recommending traditional herbal medicines that are appropriate to each patient’s health condition.

A. Experimental Design

To achieve the objectives of the experiment, three scenarios were modeled as follows:

The case of more than one diseases, such as Patient01 suffered from diarrhea that was accompanied by fever and cough.

The case of same disease with different personal health information, such as Patient02, a 6-year-old female patient suffering from diarrhea and Patient03, a 25-year-old pregnant patient suffering from diarrhea.

The case of more than one diseases with different personal health information.

B. Dataset

A total of 27 datasets were synthesized and employed in the experiment to assess the efficiency of the proposed system, consisting of:

1) Data of 27 patients that encompassed revelant characteristics of patients, including age, gender, body temperature, pregnancy status, lactation status, currently used medicines, and chronic diseases or other diseases.

2) Data of 4 diseases associated with the conventional medicine and data of 4 diseases associated with the Thai traditional medicine.

3) Data of 19 recommended herbal medicines and data of 2 conventional medicines that cannot be used in conjunction with herbal medicines.

C. Evaluation

The efficiency of the proposed system was evaluated through the use of four tools, as follows:

1) Accuracy measures the accuracy of the results compared to the target values.

$$Accuracy = \frac{A}{A+B+C} x100 \tag{1}$$

2) Precision measures the accuracy of searchable data based on the ratio between the number of data that were accurately retrieved and the total number of data retrieved.

$$Precision = \frac{A}{A+C} x100 \tag{2}$$

3) Recall measures the completeness of searchable data based on the ratio between the number of data that were accurately retrieved and the total number of accurate data in the system.

$$Recall = \frac{A}{A+B} x100 \tag{3}$$

4) F-measure (Function measure) measures the overall efficiency by combining precision and recall.

$$F - measure = \frac{2xPrecision\ x\ Recall}{Precision +\ Recall} \tag{4}$$

Where:

A means the number of herbal medicines recommended by the system and accepted by a medical specialist.

B means the number of herbal medicines recommended by a medical specialist but not by the system.

C means the number of herbal medicines recommended by the system but not by a medical specialist.

The system was tested with the data of 27 patients. The results of herbal medicine recommendations obtained from the system were examined by a specialist in the Thai traditional medicine. The efficiency of the system is presented in Table 3.

The mean accuracy rate was 80.65% and the precision rate was 87.21%. This illustrates that the herbal medicines recommended by the system were similar to that of a medical specialist and consistent with the recommendations from the herbal medicine manual according to the national list of essential medicines.

The rate of recall was 91.46%, which demonstrates that the developed ontology and the constructed rules were capable of searching data in a complete manner.

The value of F-measure was 89.29%, which suggests that the system was able to offer satisfactory recommendations of herbal medicines and serve as a tool to support physicians in selecting herbal medicines that are appropriate to the health condition of each patient.

TALBE III. ASSESSMENT RESULT FROM A MEDICAL SPECIALIST

Scenario	**Score**			**Accuracy**	**Precision**	**Recall**	**F-measure**
	A	**B**	**C**				
Scenario 1	25	3	7	71.43	78.13	89.29	83.33
Scenario 2	41	4	2	87.23	95.35	91.11	93.18
Scenario 3	9	0	2	81.82	81.82	100.00	90.00
Average	**75**	**7**	**11**	**80.65**	**87.21**	**91.46**	**89.29**

VI. CONCLUSION AND FUTURE RESEARCHES

Concerning the complication associated with the recommendation of traditional herbal medicines that correspond to each patient's health condition, this research thereby proposed a personalized recommendation system using an ontology-based technology and inference engine. In addition, the traditional herbal medicine ontology was developed to encompass the instructions for use and the contraindications of traditional herbal medicines. Rules were also constructed to obtain personalized recommendation of traditional herbal medicines by taking into account the health condition of each patient and other relevant information. According to the results, the system was capable of providing recommendations of traditional herbal medicines that are appropriate to each patient's health condition and consistent with the recommendations of a specialist in the Thai traditional medicine.

Recommendations for future researches include: (1) acquiring knowledge on traditional herbal medicine recommendations by relying on the past experiences of medical specialists as the knowledge base of the system; (2) proposing a traditional herbal medicine recommendation system in the form of case-based reasoning; and (3) incorporating new techniques into the system to enhance accuracy, such as Fuzzy logic.

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