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Development of a knowledge-based medical expert system to infer supportive treatment suggestions for pediatric patients

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This paper discusses the design, implementation, and potential use of an ontology-based mobile pediatric consultation and monitoring system, which is a smart healthcare expert system for pediatric patients. The proposed system provides remote consultation and monitoring of pediatric patients during their illness at places distant from medical service areas. The system not only shares instant medical data with a pediatrician but also examines the data as a smart medical assistant to detect any emergency situation. In addition, it uses an inference engine to infer instant suggestions for performing certain initial medical treatment steps when necessary. The applied methodologies and main technical contributions have three aspects: (a) pediatric consultation and monitoring ontology, (b) semantic Web rule knowledge base, and (c) inference engine. Two case studies with real pediatric patients are provided and discussed. The reported results of the applied case studies are promising, and they demonstrate the applicability, effectiveness, and efficiency of the proposed approach.

KEYWORDS
inferencing, mobile consultation and monitoring, ontology knowledge base, pediatric diseases, rule-based medical expert systems, smart healthcare systems

1 | INTRODUCTION

Acute respiratory tract infections (ARTI) are the leading cause of under-five morbidity, with almost two million childhood deaths per year estimated worldwide [1]. Accordingly, respiratory infections are the most common infectious diseases in the childhood period, for example, upper respiratory infections or contagious illnesses that include otitis media, sinusitis, pharyngitis, tonsillitis, nasopharyngitis, and others. It is possible to raise the quality of life of pediatric patients and decrease parental anxiety during their child's ARTI period by allowing the patient's pediatrician to continuously monitor and diagnose from any place at any time.

M-health is a popular aspect of e-health applications that has undergone an exponential growth in recent years. The use of technological solutions in the health sector with the potential to make patients' lives easier has gradually increased with m-health. M-health systems help observe patients during treatment and provide services such as gathering medical data during the monitoring stage [2–4]. Physicians can access the data from their office via internet and examine the patients' history, currently observed symptoms, and patient's response to a given treatment [5]. In addition, smart m-health systems with a strong knowledge base can perform the inferencing step based on the data collected for many purposes [6,7]. To develop such a smart and rule-based medical expert system, the semantic Web (SW) technology [8] is a good approach.

SW technology was first proposed in [8] as an extension of the current Web and as a subset of artificial intelligence technology in which information has a well-defined meaning. The semantic approach enables better cooperation between computers and people, and it is used to create "intelligent agents" that help users find the answers to their queries more precisely via ontologies. Gruber [9] described the ontology as a conceptual language of the SW that is a specification of a conceptualization of a knowledge domain. Precisely, ontology is a controlled vocabulary that formally describes concepts and their relationships. Recently, many ontology languages have been proposed and standardized, such as resource description framework schema (RDFS) [10] and Web ontology language (OWL) [11]. According to the World Wide Web Consortium (W3C), OWL is a family of knowledge representation languages for reasoning on ontologies. OWL expresses concepts in a machine-understandable form with specific spatial terms for a specific domain.

In this paper, an ontology-based mobile pediatric consultation and monitoring system is discussed, which is a healthcare expert system for pediatric patients, and a research and development project. The proposed system includes three main parts: (a) pediatric consultation and monitoring ontology (PCMO), (b) SW rule knowledge base, and (c) inference engine.

The rest of the paper is organized as follows. Section 2 presents an assessment of the proposed system and other similar research and development projects. Section 3 presents two case studies of the mobile application of the proposed system. Section 4 discusses the system ontology—PCMO. Section 5 discusses the SW rule knowledge base and inference engine of the system. Section 6 presents the implementation of the inference engine. Finally, Section 7 discusses evaluation results of the system. Section 8 presents the summary and conclusions.

2 | RELATED WORK

2.1 | Assessment of similar research and development projects

In this section, the proposed system is compared to other research projects. The mobile application (app) of the proposed system guides parents in gathering instant medical data from their children's body such as: taking images of throat/tonsil and ear region surface, measuring instant fever, observing recent symptoms, recording lung respiratory sounds, and other signs during the ARTI period of their child. The mobile app requires creating a new pre-examination card before gathering data. At this step, parents are encouraged to attach certain add-on mobile medical apparatuses to their mobile devices for medical data gathering. Certain add-on mobile medical apparatuses and m-health solutions have also been used in research projects [12–17].

CellScope (also known as Remotoscope) [12] is a smartphone-enabled otoscope project. With a simple clip-on system, it converts a standard smartphone into a digital otoscope, which enables physicians to remotely diagnose ear infections. Parents can attach this peripheral to a smartphone camera lens and send images of their child's inner ear to physicians to make a diagnosis. CellScope aims to reduce the annual number of doctor visits for children' ear infections, currently estimated as 30 million in the United States [12].

StethoMic [13] is a low-cost digital stethoscope for off-the-shelf components of smartphones. By using powerful digital signal processing chips on modern smartphones, the StethoMic minimizes the need for custom circuitry and electronic components. StethoCloud [13] of the StethoMic runs on smartphones with Windows, Android, and legacy Java micro edition (J2ME); an iOS version of the application is currently in development. In addition, StethoCloud uses smart algorithms to provide diagnostic clinical decision support to the physicians at the point of care. StethoMic uses machine learning to accurately diagnose pneumonia, asthma, and other respiratory diseases. Many other digital stethoscope projects have features similar to StethoMic and include a database of breath sounds and smart algorithms [14–16].

VitaDock [17] (known as ThermoDock) is equipped with infrared technology for iPhone and measures instant contactless body temperature in seconds.

Compared with the aforementioned products, our proposed system collects not only one type of medical data but several types: measuring fever, taking images of the throat/tonsil and ear, recording breath sounds of lungs, instant symptoms, and so on.

Table 1 compares the functionality of our proposed system and the products mentioned above (CellScope, VitaDock, and StethoMic).

The main contributions of the proposed system compared with other research studies are the design of a smart expert healthcare system that involves (a) PCMO, (b) SW rule knowledge base, and (c) inference engine. Hence, it not only shares the gathered medical data but also examines them to suggest some medical steps using its medical inferencing rules.

2.2 | System overview and methods of gathering medical data

This section briefly discusses how (and which) medical data can be gathered from pediatric patients by using a mobile-enabled medical apparatus. We assume the use of commercial add-on mobile medical apparatuses such as CellScope, StethoMic, VitaDock, and Android Lens [18] for gathering medical data before the system can inference *supportive medical treatment suggestions*. The system users are encouraged to gather the medical data in the following way:

TABLE 1 Proposed system is compared with other m-health projects

Available functions	Proposed Sys	CellScope	StethoMic	ThermoDock
Create a disease pre-examination card	+	+	−	−
Gather throat/tonsil images by using the smartphone camera (or an attached mobile camera lens apparatus)	+	−	−	−
Gather recent ear surface and ear drum infections images by using the smartphone camera (or an attached mobile otoscope)	+	+	−	−
Take a video of a general view of the child's face via the smartphone camera (10 sec)	+	−	−	−
Measure fever via a mobile-connected infrared thermometer (or manual entry from a corrected thermometer available at home)	+	−	−	+
Obtain lung respiratory sound records	+	−	+	−
Provide instant consultation by a registered pediatrician for parents anytime	+	+	+	−
Provide instant messaging environment with a registered pediatrician anytime	+	−	−	−
Keep and monitor the latest observed symptoms as medical records of a pediatric patient via a mobile pre-examination card	+	−	−	−
Log the latest used medications and time of use (antibiotic, antipyretic, and so forth)	+	−	−	−
Log the latest applied medical support steps.	+	−	−	−
The system has its own inferencing mechanism (SWRL medical rule knowledge base) that identifies instant emergencies to give alert automatically and suggest appropriate supportive medical steps to users	+	−	−	−
Runs on both iOS and Android smartphones	+	−	+	−

- *Image of the ear surface:* A pediatric otoscope apparatus is installed on the camera objective (Figure 1A).
- *Image of the throat:* An installed apparatus includes a lens to further strengthen the camera lens (Figure 1B).
- *Measuring the fever:* An infrared/digital thermometer is installed in the socket port of the phone (Figure 1C).
- *Lung/respiratory sound:* A digital stethoscope can be installed in the jack port of the phone (Figure 1D).

In research on gathering the images of the ear surface and throat/tonsil using the proposed system, it is observed that recent smartphones have good image resolutions and LED lighting. For this reason, a front camera lens and mobile-connected pediatric otoscope are optional in the final product. Using fewer devices makes the product more economical. In addition, in the proposed system, parents can enter the latest "fever" value manually by using any verified thermometer available at home. Therefore, using a mobile-connected infrared digital thermometer is also optional.

The system is planned to be marketed as a medical pediatric kit that contains a membership number, mobile-connected infrared digital thermometer (optional), front camera lens (optional), mobile-connected pediatric otoscope head part (optional), and mobile-connected digital stethoscope. This project does not consider the development of aforementioned commercial mobile medical apparatuses used in the proposed system. Instead, the research project is concentrated on developing the system with its (a) PCMO, (b) SW rule knowledge base, and (c) inference engine. The parts of the system are detailed in Sections 4, 5, and 6.

3 | CASE STUDY

Before discussing technical contributions, this section describes two scenarios with the inference step that suggests instant supportive medical treatment steps to users. The first scenario is an ordinary medical suggestion, while the second one is an emergency case. A written informed consent was obtained from the parent of the patient for publication of this case study and any accompanying images without indicating real names of the patient and parent. Hence, the real names have not been used. The name of the father who used the mobile system is replaced with "James Brown." The name of the child (patient) is replaced with "Susanne Brown." The mobile app of the system is titled as "Mobile pediatric consultation and monitoring system (mPCMS)" as shown in Figure 2A.

3.1 | Scenario 1

According to the steps mentioned above, the parent "James Brown" (id: 44937141779) logs in the mobile application of the system, clicks the "Add Child" button (Figure 2A), and creates a new account for his child "Susanne Brown" (id:

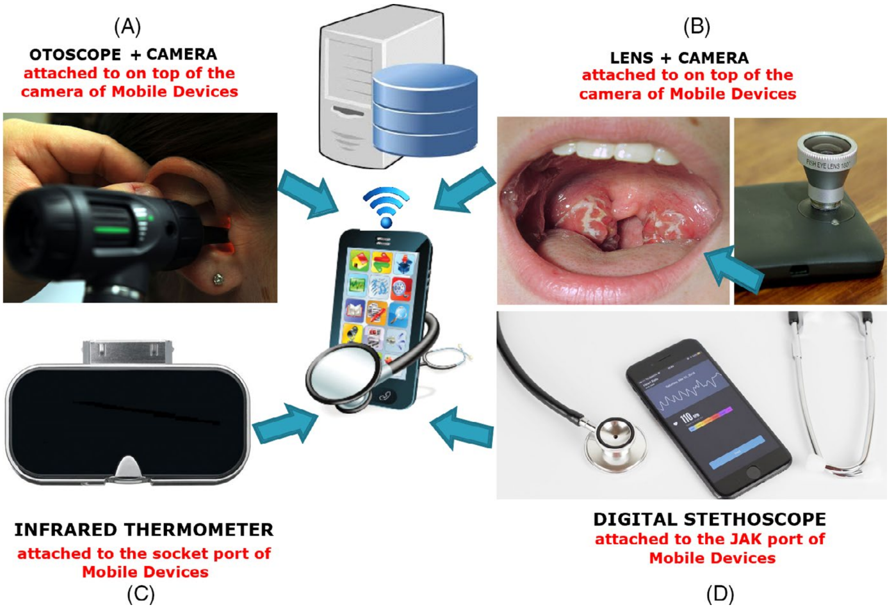

FIGURE 1 System overview and methods of gathering medical data: (A) attached to top of smartphone camera(https://commons.wikimedia.org/wiki/File:Otoscope_exam.JPG); (B) attached to top of smartphone camera (https://upload.wikimedia.org/wikipedia/commons/4/4a/Pos_strep.JPG, https://commons.wikimedia.org/wiki/File:Fisheye_phone_lens_collage_with_example_image.jpg); (C) attached to socket port of smartphone (https://commons.wikimedia.org/wiki/File:Vitalwert-Messmodul_ThermoDock.jpeg); (D) attached to jack port of smartphone (https://foto.wuestenigel.com/heart-beat/)

44937141788). In this menu, users can create separate accounts for each of their children. In the next logins, the parent can see the list of accounts created for his/her children (Figure 2A). In the next page, the parent can create a "New Examination" card for his/her child named "Susanne Brown" (Figure 2B). The system creates a new examination card for "Susanne Brown" and shows a medical data collection page. As seen in Figure 2C, an empty "New Examination" card is opened, which includes "No Symptoms," "0/6 Recorded Respiratory Sound," "0/2 Recorded Image of Ear Region Surface," "0/1 Recorded Image of Throat," "Measurement of fever is not completed," "0/1 Recorded Image of Face." When the parent clicks the "Symptoms" button, the system asks the parent to select the actual symptoms observed for the child. In our example, the parent enters the symptoms as "Nasal discharge," "Cough," "Weakness," and "Muscle Pain" (Figure 2D). In the further steps, the system guides the parent to take images of the throat/tonsil/ear/face, to measure the fever, and to record the respiratory sound of the child, general view of the child's face, and so on. As seen in Figure 3, the "New Examination" card of the system requires the installation of the mobile-enabled apparatus in certain order and uploads all the gathered data. The data gathered are sent to the database through Wi-Fi. The data are collected as follows:

3.1.1 | Lung/respiratory sound

A digital stethoscope [13] is installed to the jack port of phone. The sound data (maximum 10 seconds) is collected from six different points of the back of the child, and recorded in the data collection menu (Figure 3A).

3.1.2 | Image of ear surface

A pediatric otoscope apparatus [12] is installed on the camera objective and uses the flash of mobile phone. The images of right and left inner ears are uploaded using the data menu (Figure 3B). Here, taking the surface images of right and left ears on a daily basis will help to define or measure the presence, amount, viscosity, color, and similar features of the ear infection, especially during the otitis media disease period.

3.1.3 | Image of the throat/tonsil

An add-on lens [18] is installed to further strengthen the camera lens. The flash of the phone is used. The parent takes an image of the throat/tonsil and uploads it to the card. In this step, the images are taken without any additional lens. It is observed that high-quality images ($\geq$ 5 MP) can be obtained (Figure 3D).

3.1.4 | Measuring the fever

If a smartphone-enabled infrared/digital thermometer apparatus [17] is installed in the socket port of the smartphone, the instant fever data is scanned at 3 cm distance from the forehead of the child. It is measured and automatically uploaded to the mobile screen (Figure 4A). Alternatively, the parent

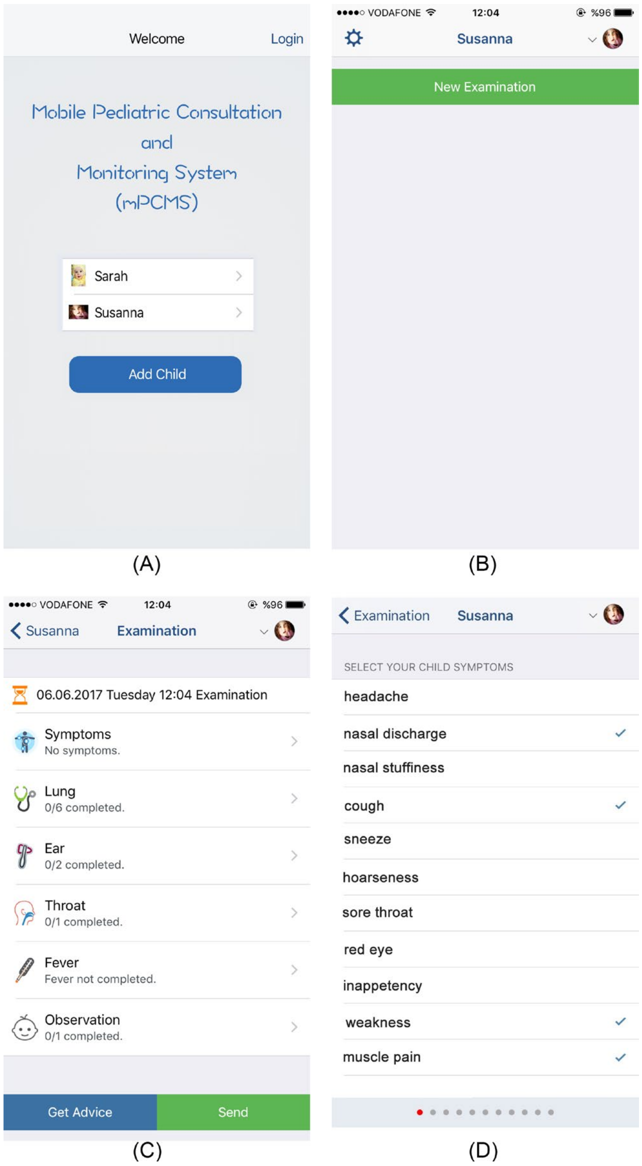

FIGURE 2 Newly opened "New Examination" cart assists the parent "James Brown" (id: 44937141779) in collecting data: (A) Parent clicks on "Add Child" to register his/her child; (B) "New Examination" card option; (C) Empty "New Examination" card; (D) Instantly observed symptoms selected by the parent

can use any other verified thermometer device for home use and enter the medical data manually to the system.

Thus, this paper has already described which apparatuses are used, which medical data is collected, and how the parent fills a new pre-examination card. The next section discusses how the system produces instant supportive medical treatment steps as the first aid after gathering data for guiding the parent.

3.2 | Generating supportive medical treatment suggestions

Some of the data gathered by parents up to now (such as lung/respiratory sounds, images of the ear surface/throat/tonsil, and video records of patient's face views) are not sent to the inferencing mechanism but are presented to a registered pediatrician to perform a remote offline consultation or get an opinion and evaluation of the pediatrician at any time. To generate supportive medical treatment suggestions for the parents, system uses ***only*** the following data:

- Instant fever data.
- Selected instant medical symptoms from the pre-examination card ("nasal discharge," "cough," "weakness," "muscle pain," and so on).
- The name and time of medicine(s) given previously by the parent to reduce fever.
- The presence of any medical intervention made by the parent previously ("cold shower," "cold towel," and so on).

All gathered medical data are seen on "*New Examination*" card (before data gathering in Figure 2C and after data gathering in Figure 4B). In the next step, it is asked if any antibiotic medication prescribed by the registered pediatrician at any time has been used recently. If the parent chooses "*YES*" option, the name of antibiotic medication is asked. In this screen, the names of all medications prescribed by the pediatrician before are displayed as shown in Figure 4C. Next, the parent needs to select the medication that was given to his/her child to reduce fever from the list (eg., *Paracetamol*, *Ibuprofen*). At this phase, the parent chooses one of the medication names listed (*Paracetamol*) as shown in Figure 4C. In the next step, as shown in Figure 4D, the system asks the parent how long the "*Paracetamol*" has been given to the child before. Besides that, as shown in Figure 4E, the system asks if any medical treatment such as cold shower and cold towel has been applied to child at home environment. After this step, finally system requests taking and uploading 10-second video of the face view of child via mobile camera in a well-lit home environment. Thus, a pediatrician registered in the system can examine the image of the child's face for signs of faintness, cyanosis, reddening, and so on.

According to the first scenario, the suggestions are provided by the inference engine of the proposed system as shown in Figure 4F:

- **Suggestion 1:** Adjust the room temperature.
- **Suggestion 2:** Take off child's clothes and keep him/her naked.
- **Suggestion 3:** Measure the temperature again ½ hour later.

3.3 | Scenario 2

The second scenario describes an emergency case when the system can detect the emergency and give a warning. In our

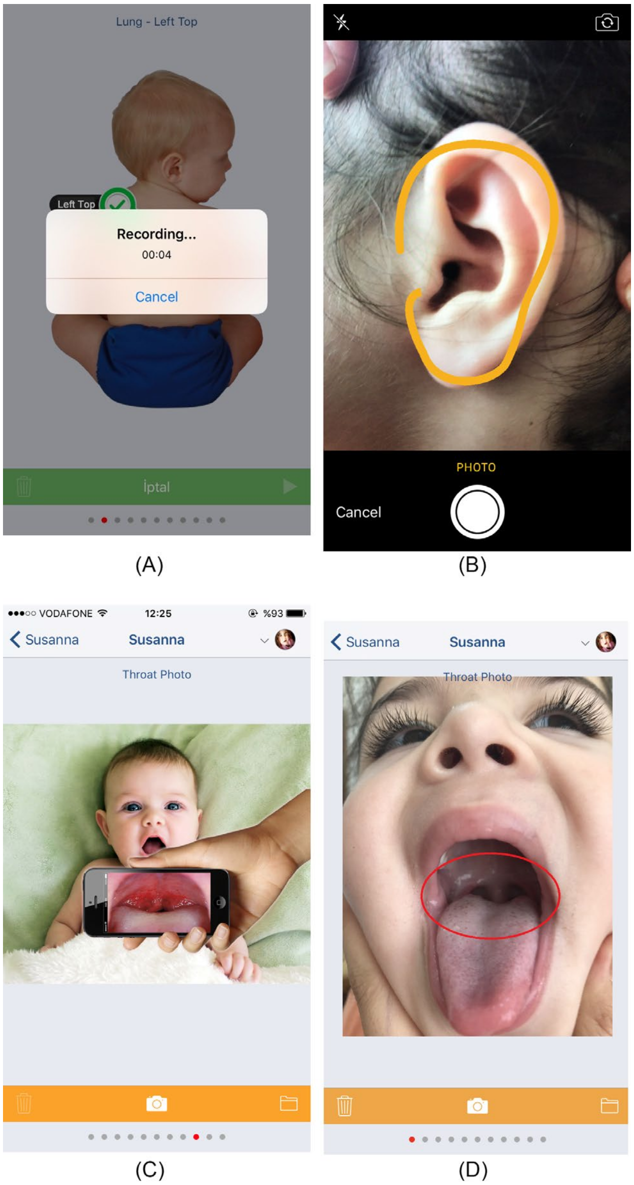

FIGURE 3 Medical data collection of lung respiratory sounds and images of throat/tonsil/ear of the child patient: (A) Recording 10 sec. lung sound; (B) Ear region surface picture is taken; (C) Taking the throat photo; (D) Throat picture is taken

emergency case scenario, the following ***medical data*** gathered by the parent are available:

Symptoms: "headache," "nasal stuffiness," "sneezing," "hoarseness," "sore throat," "red eye," "in appetency," and "weakness" (Figure 5A),

- **Fever:** 40.8°C,
- **Medication Use:** NO,
- **Medication Type: -**
- **Time of Medication Use: -**
- **Cold Shower Treatment:** NO.

According to the data, the result of ***supportive medical treatment suggestions*** is listed as shown in Figure 5B:

- **Suggestion 1**: Take off child's clothes and keep him/her naked.
- **Suggestion 2**: Give fever-reducing medication that was prescribed by his/her pediatrician.
- **Suggestion 3**: Take the child to the hospital immediately.

After producing proper suggestions for an emergency case, a medical care team is evoked by the system automatically to immediately communicate with the parents (through their registered numbers in the system) to confirm the emergency situation and guide them. Alternatively, when an emergency is detected, the system calls an ambulance paramedic team automatically. The generated suggestions aim to make parents feel more comfortable and safer, especially for the families having their first child or a repetitively sick child. In addition, keeping the medical data gathered over time in a database and being able to share them with a pediatrician at any time provide incredible substantial worth in taking rapid action. Especially, in cold winter months, 48% of patients in emergency services consist of the pediatric patients and patients in situations that require no emergency treatment but preliminary examination such as common cold, fever, vomiting, and nausea [19]. Considering the traffic between the home and hospital and the intense conditions that occur in hospital policlinics sometimes, being able to share the data with a specialist directly through such systems is a way to reduce the anxiety.

As a result, under the light of data collection, a pediatrician performs his/her consultation based on the certain priorities and rules while making medical suggestions for the patient. These medical rules constitute the basis of semantic-based rules of the proposed system. In the next sections, the details of the PCMO and its SW rule knowledge base are discussed.

4 | ONTOLOGY KNOWLEDGE BASE

The characteristics and knowledge related to ARTI diseases (considering patients' profile, applied medical treatments, possible symptoms, and so forth) are modeled as concepts, properties, or relations in the system ontology. We call it "pediatric consultation and monitoring ontology (PCMO)." The ontology is coded in OWL and developed by using the Protégé ontology editor [20]. Figures 6 and 7 depict some portions of the ontology in Protégé. The ontology starts with "*Thing*" class that is divided into various subconcepts such as "*child*," "*symptom*," "*case*," "*suggestion*," "*user*," and so forth. In addition, these concepts may also involve

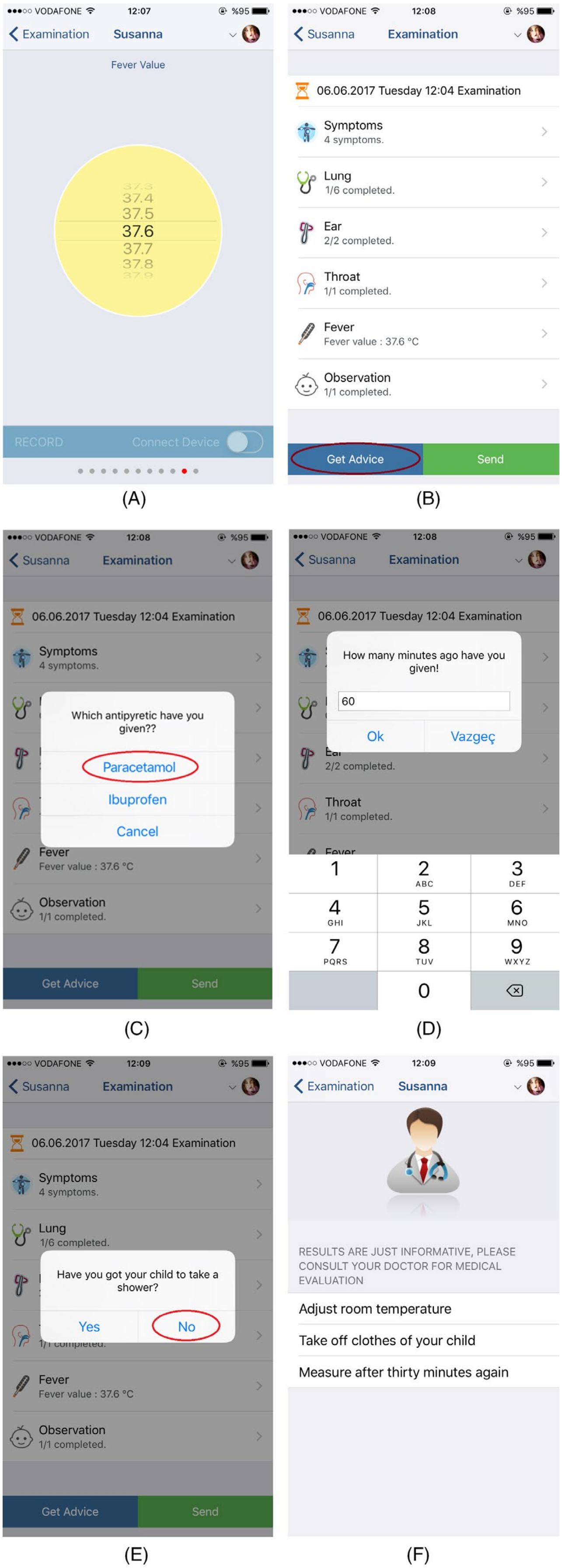

FIGURE 4 iOS mobile app presents "Supportive Medical Treatment Suggestions" to the parent: (A) Parent enters the child's fever value as 37.6°C; (B) After completing card, parent selects "Get Advice."; (C) System asks which medicine is given (Paracetamol); (D) System asks how many min. ago the medicine is given (60 mins); (E) System asks if any medical treatment has been applied (No); (F) System infers 3 supportive medical treatment suggestions

several subconcepts such as "*suggestion name*," "*symptom name*," "*disease name*," "*measure step*," "*fever*," "*location*," and so on. Based on those concepts, many object-type or data-type properties are generated such as "*has child id*," "*has age value*," "*has temperature*," "*has drug time*," "*has last suggestion id*," "*has measure step*," "*has minor symptom count*," "*has local symptom count*," "*has major symptom count*," and so forth. Those properties are created to establish interclass relations and to interpret OWL individuals. Another semantically structured relation that belongs to the classes is "*OWL individual*" declarations. The class "*symptom name*" in the ontology contains various OWL individuals such as "*sore throat ache*," "*fever*," "*discharge*," "*sneeze besides cough*," "*headache*," and so forth. Most of those symptom concepts are widely used in the literature related to diseases leading to lower/upper respiratory tract infections. In addition, the system ontology is developed based on the inspiration from pediatric disease ontology named PEDTERM [21], which is a research project published as open source in BioPortal. PEDTERM ontology contains the classes and information related to health and growth of children younger than 21 years. PEDTERM is developed with the contributions of National Institute of Pediatric and Human Growth.

Consequently, the structure of the PCMO consists of 20 classes, 39 object-type and data type properties, 201 OWL individuals, and 61 SW rules (Figure 6). Even though it is currently limited (compared with the conceptual model of the ARTI disease domain), the PCMO can be developed by ontology engineers over time. Accordingly, the fourth version of the PCMO is shared as open source to the BioPortal ontology repository [22]. Technical details about the semantic rules and inferencing mechanism running on those rules to generate ***supportive medical treatment suggestions*** are presented as follows.

5 | INFERENCING SUPPORTIVE MEDICAL SUGGESTIONS

The system has its own semantic rule knowledge base. The knowledge base includes medical rules, which represent 61 different medical cases (Figure 6). Almost all rules consider the following data:

- **Recent body temperature** (“has temperature” property).
- Number of **major, minor,** and **local symptoms** observed during the examination (for example, “has minor symptom” count property).
- **Medications used recently, and time of use** (“has drug” and “has drug time” properties).
- **Presence of a medical treatment for cold applied recently** (“is shower” property) ⇒ only 1 of 61 different Case definitions will be our inferencing result (Case 02 in Figure 7).

Rules are generated by using the *semantic Web rule language (SWRL)* [23], which is submitted to be a standard of W3C. The aim of the SWRL knowledge base is to infer ***supportive medical treatment suggestions*** to guide parents according to the instant medical data gathered. SWRL, which is based on OWL, is a strong and deductive rule description language. SWRL is influenced by OWL sublanguages that are used to create rules based on an ontology knowledge base by containing top-level abstract syntax in Horn-like rule structure. SWRL rules consist of atoms, and every atom contains OWL classes, OWL properties (OWL object, data, or annotation type of properties), and OWL individuals. Developed rules are localized as parts of the ontology. System is run by OWL individuals together with the rules on inferencing software located in Web services. Inferencing via SWRL rules is performed by using an OWL-based reasoner. Some of well-known OWL-based reasoners are Pellet [24], Fact++ [25], and RacerPro [26]. To enable the developed system to infer according to the rules in its SW rule knowledge base, Pellet reasoner is preferred. Pellet interprets SWRL using description logics (DL)-safe rule notion that means applying rules to only the named individuals in the ontology. This means that, during the inferencing, the process is executed only by running the individuals allocated to ontology on SWRL rules. For the “Susanne Brown” (44937141788) case, as shown at the top-right edge of Figure 7, the input values are drawn from the mobile application and then instantly embedded to the system ontology. Then, Pellet infers CASE 02 as the most suitable case. Each case indicates one or more Suggestion ID definitions. Thus, the suggestion numbers of SG 06, SG 07, and SG 12 that are connected to CASE 02 in “*has case sg id*” object type property are concluded by the system (shown with red arrow at top-right edge in Figure 7). These suggestions are observed with the property definitions in “*has suggestion name*” object type. The suggestions of “*Adjust the room temperature*,” “*Take off child's clothes and keep him/her naked*,” and “*Measure the body temperature after ½ hour again*” are offered to the parent (the bottom-right in Figure 7). The details of the rule CASE 02 are presented below.

SWRL Rule of CASE 02: USER ID(?uid), HAS CHILD ID(?uid, ?cid), HAS LOCAL SYMPTOM COUNT(?cid, ?lsc), lessThan(?lsc, 5), HAS MAJOR SYMPTOM COUNT(?cid, ?masc), lessThan(?masc, 1), HAS MINOR SYMPTOM COUNT(?cid, ?misc), lessThan(?misc, 3), HAS TEMPERATURE(?cid, ?t), greaterThan(?t, “37.4”^^xsd:double), lessThan(?t, “38.1”^^xsd:double), IS DRUG(?cid, true), HAS AGE IN MONTHS(?cid, ?months), greaterThan(?months, 12) ⇒ HAS CASE(?cid, CASE02).

The clarification of few inputs and the output of CASE 02 are as follows:

- **USER ID (?uid):** If “uid” is an individual of parent class, and also,
- **[HAS LOCAL SYMPTOM COUNT (?cid, ?lsc), lessThan (?lsc, 5)]:** If child “cid” has local symptoms and also if total HAS LOCAL SYMPTOM COUNT value is “lsc” and also if this “lsc” is less than “5”, and also,
- **[HAS_TEMPERATURE (?cid, ?t), greaterThanOrEqual (?t, 37.4), lessThan (?t, 38.1)]:** If temperature of child ‘cid’ is ‘t’ and also if the ‘t’ is greater than or equal the value of ’37.4°C’ and also less than ’38.1°C’,…then
- **⇒ HAS CASE (?cid, CASE02). Result for “cid” is CASE 02**.

Flow diagrams of all cases, a portion and OWL graph of PCMO, all details of CASE 02 example, and other related materials are provided in BioPortal repository [22].

6 | IMPLEMENTATION OF INFERENCE ENGINE

Web services of the system help to communicate among the client interfaces, database, and ontology knowledge base and present suitable instructions to the parents via the mobile app. To run the SWRL rules via Web services, Pellet application programming interface (API) [27] is used, which is an open source OWL DL reasoner. By importing OWL API [28] and Pellet API libraries in Java environment (see Table 2, lines 1 to 4), the inference engine and parsing mechanism on the system's ontology via Web services are developed. Each case (rule) and each suggestion as an inferencing result is drawn by translating in to Java variables during inferencing. The drawn inferencing results are transformed to *JavaScript object notation (JSON)* [29] format, and then the data transmission is ensured via RESTful services [30].

For the “Susanne Brown” (child id: 44937141788) case discussed above, the “HAS CASE,” “HAS CASE SG ID,” and “HAS SUGGESTION NAME” suggestion results are drawn from Java environment. As seen above, the function *runSWRLRule* at line 35 of Table 2 has two parameters. The first parameter is patient id. The second parameter is the

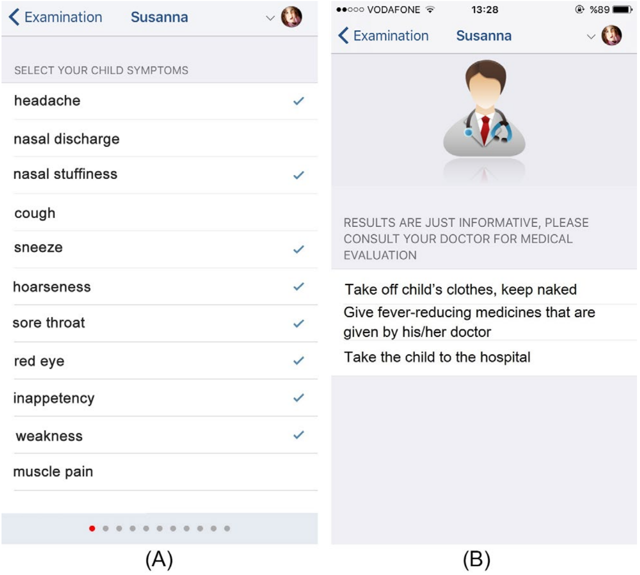

FIGURE 5 The parent enters an emergency case medical data: (A) Parent selects eight observed symptoms; (B) System presents three suggestions to the parent

examined case no via "HAS CASE" object property. When the statement runs, a case number is obtained as a result. Procedure for presenting suggestions for "James Brown" (id: 44937141779) scenario via "HAS CASE" and "HAS SUGGESTION ID" properties, CASE 02 and linked suggestion numbers are retrieved.

7 | EVALUATION OF THE SYSTEM WITH THE EXPERIMENTAL DATA SET

In total, 78 anonymous patient records were obtained from the collaborating pediatrician as the case records for the evaluation purpose. Each record contains the basic personal patient data and a medical suggestion done by the pediatrician. The evaluation of the system was carried out using these case records in the following two stages:

- **Semantic Web rule knowledge base and inference engine.** The personal and instant medical data of each patient was entered into the system interface to take consultation through the PCMO and inference engine. The system produced a medical treatment suggestion as the output for each of the patients.
- **Manual verification by the collaborating pediatrician.** Medical treatment suggestions produced by the system for each patient were then discussed with the collaborating pediatrician for verification. The pediatrician manually evaluated each of the produced suggestions of the system, went through the standard diagnosis processes on the collected dataset, and used professional reasoning to determine each patient's conditions and required medical interventions.

In the verification phase with the pediatrician, 11 missing suggestions were found in the first-round tests, and the missing suggestions were added to the consequent (head) parts of proper SWRL rules in PCMO. The results in the second round showed that the system produced correct and complete suggestions for all the patients.

The accuracy of the system performance for the first-round tests was calculated by (1), as the ratio of the number of identical outcomes (when the system's output was equal to the pediatrician's evaluation) to the total number of cases, and was equal to 0.86. The accuracy of the system performance was equal to 1 in the second-round tests.

$$\text{Accuracy} = \frac{\sum \text{System Suggestions} \equiv \text{Pediatrician Suggestions}}{\sum \text{Total Patients}} \tag{1}$$

Overall, results after the second-round tests show that the medical treatment suggestions provided by the system on the sample dataset are in line with a manual evaluation of the pediatrician. Additionally, the results also show that the OWL-based PCMO can provide accurate problem-solving reasoning while maintaining shareability and extensibility of the knowledge base. Therefore, as the number of patient cases increases, the PCMO will be enhanced and advanced by adding the missing supportive medical treatment suggestions to the system ontology in time by the experts.

8 | SUMMARY AND CONCLUSIONS

The paper discusses an ontology-based mobile pediatric consultation and monitoring system, which is a rule-based healthcare expert system for pediatric patients. The proposed system provides remote consultation and monitoring of pediatric patients during their illness at places distant from medical service areas. The system does not only share instant gathered medical data to a pediatrician but also examines the data as a smart medical assistant to detect any emergency situation. Additionally, it infers instant suggestions via its inference engine for performing certain initial medical treatment steps when necessary. Unlike other research studies, this study does not develop a mobile-connected medical apparatus or an ordinary m-health app. Instead, the main contribution of this study is a smart expert healthcare system that involves (a) PCMO, (b) SW rule knowledge base, and (c) inference engine. PCMO is formalized in OWL and implemented as a system ontology. In addition, SW rule knowledge base is formalized in SWRL and stored in the PCMO. In the rule knowledge base,

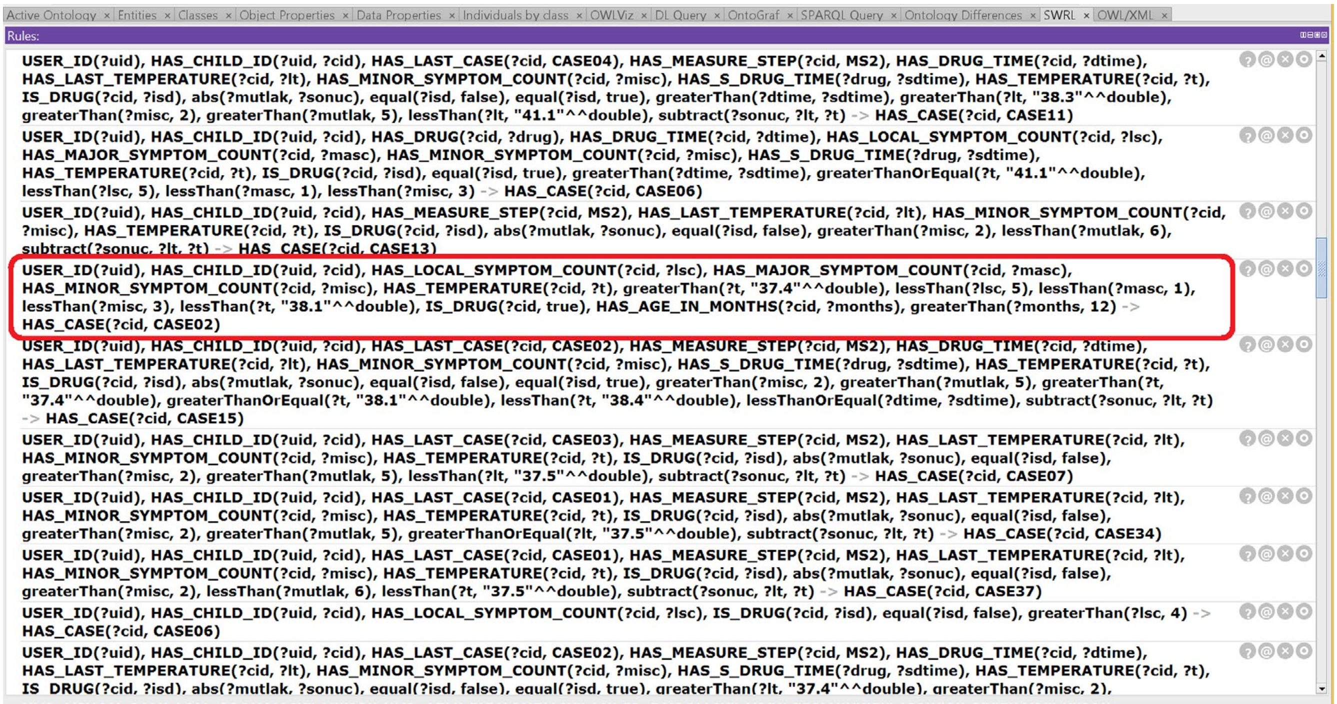

FIGURE 6 Semantic Web rule knowledge base (61 SWRL rules)

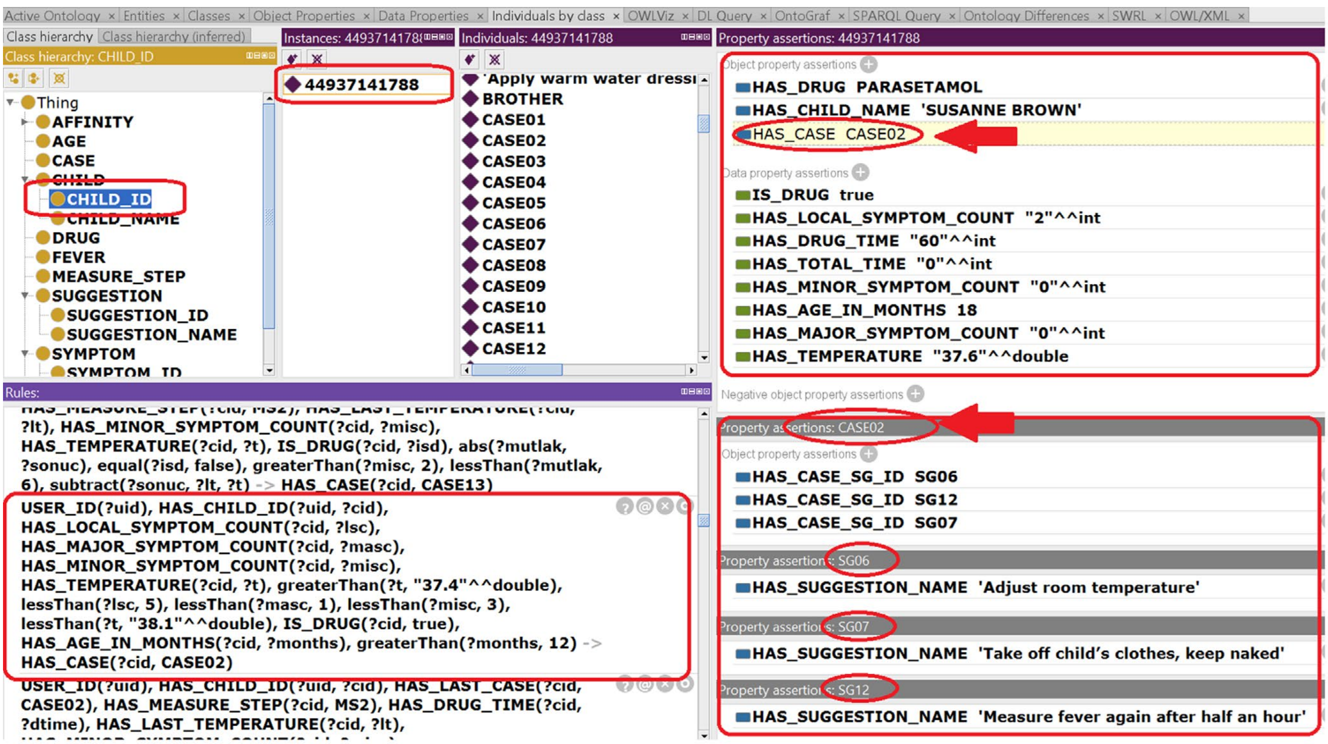

FIGURE 7 Pellet finds **CASE 02** as suitable rule for **"Susanne Brown"**

61 medical cases that are referred as semantic-based medical rules are developed by cooperating with pediatricians and ontology engineers. Each case holds several *supportive medical treatment suggestions* that can be applied at home as the first aid. The rules examine the medical data gathered from patients such as instantly observed symptoms, last fever, most recently used drug and its time, existence of most recently applied treatment in addition to patient's

TABLE 2 Procedure of inferencing in the system

```
import com.clarkparsia.pellet.owlapiv3.*;
import org.semanticweb.owlapi.apibinding.*;
import org.semanticweb.owlapi.io.*;
import org.semanticweb.owlapi.model.*;

public static final File localLocation_IRI = newFile("../PCMO.owl");
public static final IRI Base_IRI = IRI.create("http://.../PCMO");
OWLOntologyManager m = OWLManager.createOWLOntologyManager();
OWLDataFactory f = OWLManager.getOWLDataFactory();
OWLOntology o = null;

    public List runSWRLRule(String id, String OTP) {
        try {
            o = m.loadOntologyFromOntologyDocument(localLocation_IRI);
            PelletReasoner r = PelletReasonerFactory.getInstance().createReasoner(o);
            OWLNamedIndividual indv = f.getOWLNamedIndividual(IRI.create(Base_IRI + id));
            OWLObjectProperty op = f.getOWLObjectProperty(IRI.create(Ont_Base_IRI + OTP));
            NodeSet<OWLNamedIndividual> value = r.getObjectPropertyValues(indv, op);
            for (OWLNamedIndividual nmindividuals : value.getFlattened()) {
                String str = nmindividuals.toString();
                if (str!= null) {
                    list.add(str);
                }//if close
            }//for close
            m.removeOntology(o);
        } catch (Exception e) {
            System.out.println("Could not create ontology:" + e.getMessage());
        }
        System.out.println(list);
        return list;
    }
    public static void main (String [] args) {
        OntologyFunctions obj = new OntologyFunctions();
        List<String> list1 = obj.runSWRLRule("44937141788", "HAS_CASE");
        List<String> list2 = obj.runSWRLRule("44937141779", "HAS_SUGGESTION_ID");
.
.
.
    }//close main
    }//close class
```

age, gender, height, weight, and so forth. The system has its own mobile application that provides and guides how to gather medical data before suggesting suitable supportive medical treatment suggestions to its users through the inference engine. Several case studies from real pediatric patients were analyzed and all retrieved results of the case studies were verified by the pediatricians and ontology engineers. Two case studies were provided to discuss how the system works in the paper. The system does not consider any other medical data gathered (for example, images of throat/tonsil and ear region surface, recent fever, instantly observed symptoms and records of lung respiratory sounds, and so forth) during inferencing process for now. To improve the proposed system, a new image processing mechanism will be included to examine the instantly gathered images of throat/tonsils and ear region surfaces and then produce a time-dependent recovery levels of some pediatric diseases over time. As a result, the reported results of applied case studies are promising in demonstrating the applicability, effectiveness and efficiency of the proposed system. Such a system can be extensively used in home, dormitory, nursery, and hospital or school environment. The system is expected to be useful for patients and all other people who worked as pediatric healthcare professional or researching in this area.

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[1]http://www.acibademinternational.com/

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[2]http://www.semantica.com.tr/en

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APPENDIX

Updated version of the OWL form of PCMO, logical diagrams of all medical cases, OntoGraph of PCMO, all other related materials are provided at Bio portal repository [22]. Available from: http://bioportal.bioontology.org/ontologies/PCMO.