Chapter 24
Intelligent Personal Health Record

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Abstract

Web-based personal health records (PHRs) are widely available to ordinary consumers at present, but the existing PHR systems have limited intelligence and can fulfill only a small portion of users' healthcare needs. Previously, we proposed the concept of intelligent PHR (iPHR) to improve PHR's capability and usability. By introducing and extending expert system technology, Web search technology, natural language generation technology, database trigger technology, and signal processing technology into the PHR domain, iPHR can automatically provide users with personalized healthcare information to facilitate their activities of daily living. This chapter presents an overview of our iPHR system that currently provides four functions: guided search for disease information, recommendation of self-care activities, recommendation of home health products, and continuous user monitoring.

Keywords: Personal health record, Search engine, Expert system, Natural language generation, Trigger, Nursing, Patient monitoring, Consumer health informatics

24.1 Introduction

As a result of the deployment of several major Internet companies including Microsoft [21], WebMD [27], and Office Ally [22] over the past few years, Web-based personal health records (PHRs) have now become widely available to ordinary consumers. These PHR systems enable consumers to actively manage their health records and subsequently their health through a Web interface, but have limited intelligence and can fulfill only a small portion of users' healthcare needs. To improve PHR's capability and usability, we previously proposed the concept of an intelligent PHR (iPHR) [13, 17, 18] by introducing and extending expert system technology, Web search technology, natural language generation technology, database trigger technology, and signal processing technology into the PHR domain.

iPHR serves as a centralized portal for automatically providing users with comprehensive and personalized healthcare information to facilitate their activities of daily living. Due to a lack of health knowledge, consumers often are unaware of their healthcare needs and/or unable to identify proper keywords to search healthcare information [20]. To address this problem, iPHR extensively uses health knowledge to (a) anticipate users' needs, (b) guide users to provide the most important information about their health condition, (c) automatically form queries, and (d) proactively push relevant healthcare information to users whenever their potential need for it is detected. In this chapter, we use the term "health knowledge" to refer to all categories or types of knowledge related to healthcare, e.g., disease diagnosis knowledge and nursing knowledge.

iPHR provides its intelligent functions to users via a Web interface. On the right side of the main Web page of iPHR, there are multiple buttons, one for each intelligent function. After clicking a button, the user is directed to a Web page for executing the corresponding function. At present, our iPHR system provides four functions covering almost one thousand health issues:

(1) guided search for disease information,

(2) recommending self-care activities,

(3) recommending home health products, and

(4) continuous user monitoring.

Each of the first three functions can be implemented as a standalone health search engine outside of a PHR system. However, with the support of a PHR system, these three functions can be performed more effectively. In comparison, the fourth function of continuous user monitoring depends on the PHR system.

As shown in Figure 24.1, in addition to a standard PHR system, iPHR has a number of other components including a discrete event analysis system, a signal processing system, a trigger system, a natural language generation system, a health knowledge base, an expert system, and a search system. At a high level, the dashed arrow path near the bottom of Figure 24.1 illustrates the workflow of the first three functions of iPHR. The expert system uses health knowledge to convert information in the PHR into a set of keyword phrases termed "search guide information," which reflects the user's health condition and healthcare needs. Then the Web search engine uses this search guide information as seeds to retrieve personalized healthcare information. The solid arrow paths in Figure 24.1 illustrate the workflow of the fourth function of continuous user monitoring. The description of that workflow is provided in Section 24.5.

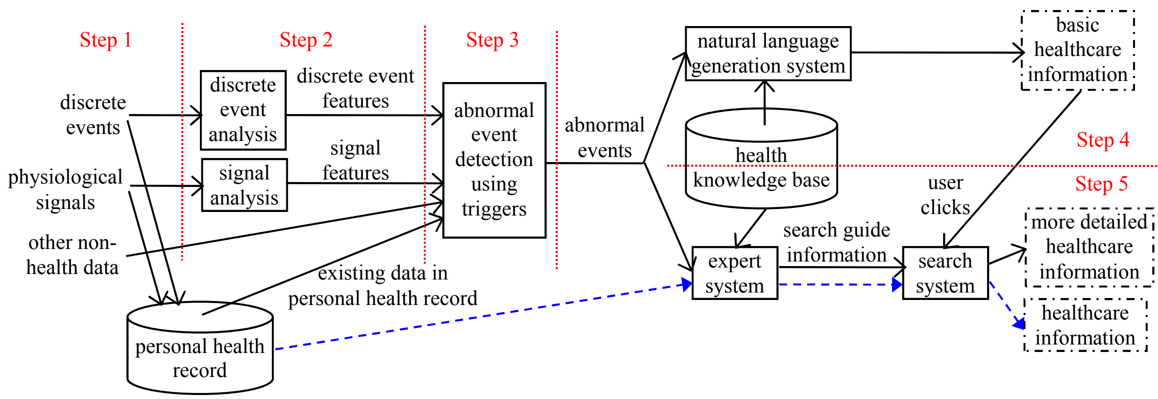

Figure 24.1 Architecture of the intelligent personal health record system.

In the rest of this chapter, we present an overview of the four functions of iPHR one by one. Interested readers can find the details of our design rationale and implementation techniques of these four functions in our previous publications [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19].

24.2 Guided Search for Disease Information

iPHR includes our intelligent medical Web search engine called iMed [8, 9, 10, 14, 15] to help users find disease information related to their health condition. The main idea of iMed is to use disease diagnosis knowledge and an interactive questionnaire to guide users to provide the most important information about their health condition and to automatically form queries. This eliminates the challenge for users to come up with appropriate medical keyword queries on their own.

iMed uses diagnostic decision trees written by medical professionals [5] as its built-in disease diagnosis knowledge. As shown in Figure 24.2, each diagnostic decision tree corresponds to either an objective sign (e.g., low blood pressure) or a subjective symptom (e.g., headache). In a diagnostic decision tree, each node that is neither a leaf node nor the parent of a leaf node represents a question that iMed can ask. Different child nodes of this node correspond to different answers to this question. The medical phrases in a leaf node are the topics (typically diseases) potentially relevant to the user's health condition.

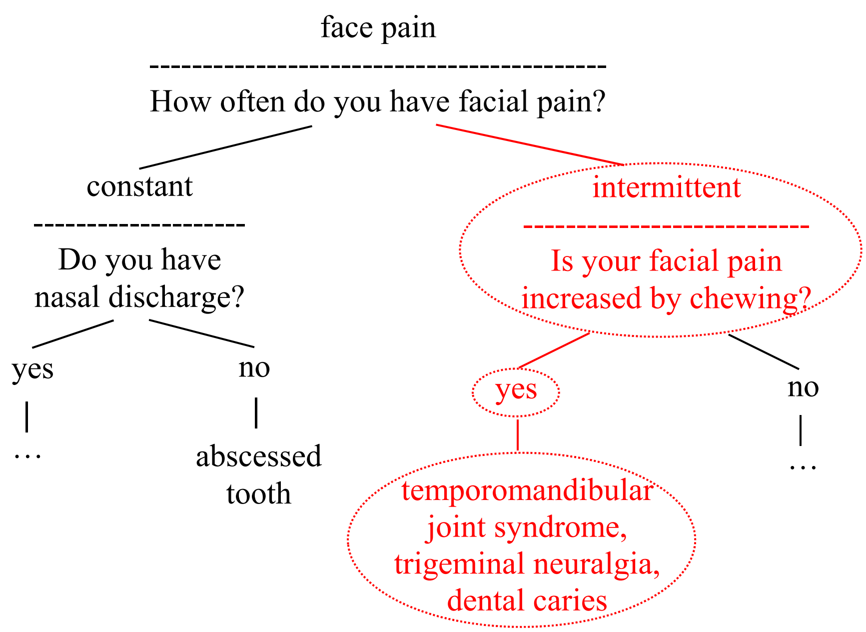

Figure 24.2 The diagnostic decision tree for the symptom "face pain" [5].

At a high level, iMed works in the following way. The user is first presented with a list of signs and symptoms, from which he selects the ones that he is currently having. Then iMed asks questions related to these selected signs and symptoms and lists possible answers to these questions. Based on the answers selected by the user, iMed navigates the corresponding diagnostic decision trees and eventually reaches multiple topics potentially relevant to the user's health condition. For each of these topics, iMed automatically uses the topic name to form a query to retrieve some related Web pages. Moreover, iMed presents a set of predetermined aspects (e.g., symptom, diagnosis, treatment, and risk factor). If the user clicks a particular aspect of the topic, iMed automatically forms a query by combining the aspect name and the topic name and uses this query to retrieve Web pages related to this aspect of the topic. In this way, without the need to form any medical keyword query by himself, the user can find disease information that is potentially related to his health condition.

For example, Figure 24.2 shows the diagnostic decision tree in Collins [5] for the symptom "face pain." If "face pain" is the only symptom chosen by the user, iMed's first question is "How often do you have facial pain?" If the user selects the answer "occasionally, from time to time" to this question, iMed's next question is "Is your facial pain increased by chewing?" If the user selects the answer "yes" to the second question, iMed reaches multiple topics including dental caries.

A typical user has little health knowledge and frequently encounters challenges during the entire disease information search process. To address this problem, iMed offers various kinds of suggestions to provide help. If the user suspects that he answered questions incorrectly, he can access alternative answers to the questions suggested by iMed. To facilitate the user to quickly digest search results and refine his inputs, iMed suggests diversified and related medical phrases. iMed also suggests signs and symptoms related to the user's health condition.

24.3 Recommending Self-Care Activities

iPHR can automatically recommend self-care activities (SCAs) based on the user's health issues [16, 17]. The user can click each nontrivial SCA to find various detailed implementation procedures for it on the Web. The main idea of this SCA recommendation function is to use nursing knowledge presented in standardized nursing languages [7].

The nursing informatics community has systematically organized nursing knowledge into multiple standardized nursing languages [7]. At present, iPHR's knowledge base includes two such standardized nursing languages covering the entire nursing domain: NANDA-I nursing diagnoses and NIC nursing interventions. NANDA-I represents North American Nursing Diagnosis Association International whereas NIC represents Nursing Interventions Classification. A *NANDA-I nursing diagnosis* is a clinical judgment about individual, family, or community responses to actual or potential health problems [1]. A *NIC nursing intervention* is a treatment that can be performed to enhance patient/client outcomes [3].

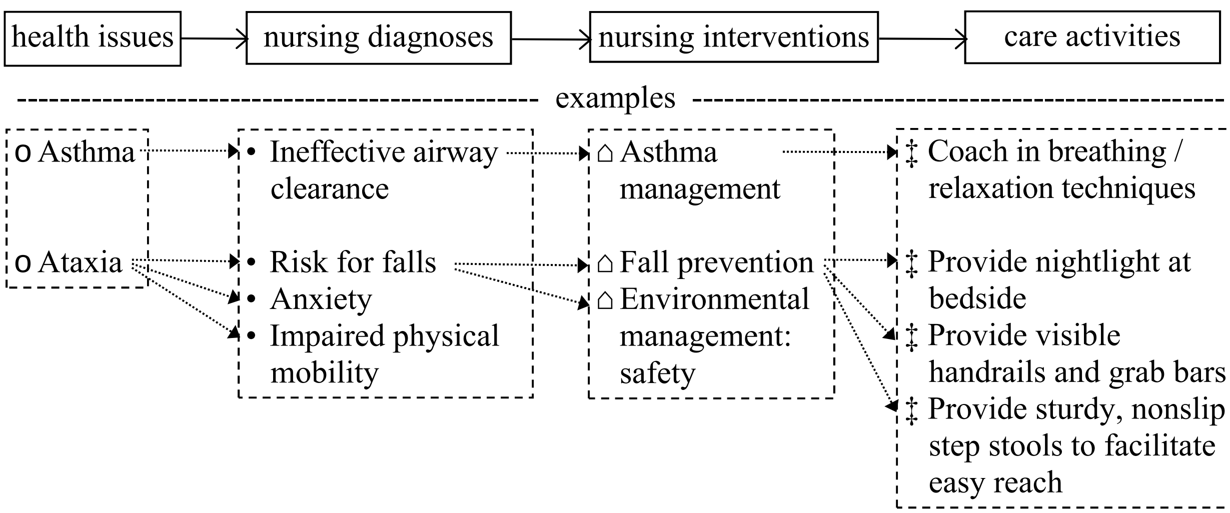

Figure 24.3 Linking health issues to care activities.

As shown in Figure 24.3, each health issue links to one or more NANDA-I nursing diagnoses [1]. Every nursing diagnosis usually links to 10 or more NIC nursing interventions [7]. Each nursing intervention includes multiple *care activities* that are used to implement it [3]. In this way, each health issue is connected to multiple care activities via the linkage provided by nursing diagnoses and nursing interventions. Nurses, patients, and/or caregivers can perform these care activities to achieve desirable outcomes for this health issue. For iPHR, we focus on SCAs that patients and caregivers can perform at home or in the community because iPHR is designed to be used by consumers.

At a high level, iPHR's SCA recommendation function works in the following way. iPHR automatically extracts from PHR the user's current health issues (e.g., diseases), uses the linkage method mentioned above to find all of their linked SCAs, and then displays these SCAs as a prioritized hierarchy. A SCA can have one or more aspects. For each aspect of a nontrivial SCA, a hyperlink is added to the displayed Web page. Also, a pre-compiled phrase is stored in iPHR's knowledge base as the SCA search guide information of this aspect. If the user clicks this hyperlink, iPHR will submit this phrase as a query to a large-scale health Web search engine. Then by reading the search results returned by this search engine, the user can find various, detailed implementation procedures for this aspect.

For example, as shown in Figure 24.3, the health issue asthma links to the SCA "Coach in breathing/relaxation techniques." For the breathing aspect of this SCA, the pre-compiled phrase "asthma breathing techniques" retrieves the following top results: (1) the Buteyko method for breathing (http://www.correctbreathing.com/), (2) two new breathing exercises for asthma (http://www.sciencedaily.com/releases/2008/05/080528095853.htm), (3) a video teaching the pranayama breathing method for asthma (http://www.youtube.com/watch?v=vplrJtp3zB4), and (4) the book "Reversing Asthma: Breathe Easier with this Revolutionary New Program" with a chapter on teaching breathing techniques (http://www.amazon.com/Reversing-Asthma-Breathe-Revolutionary-Program/dp/0446673633).

It is not uncommon for a person to have multiple health issues simultaneously (e.g., comorbidities). In this case, a SCA that is suitable for a single health issue can become undesirable in the presence of another health issue. This is called contraindication in healthcare [2]. For instance, the health issue cancer is a contraindication for the SCA massage because massage increases lymphatic circulation and hence may potentially facilitate cancer to spread through the lymphatic system. In the case where the user has multiple health issues simultaneously, iPHR uses a hierarchical propagation method based on the medical terminology of International Classification of Diseases (ICD-10) [6] to automatically detect contraindicated SCAs so that they will not be recommended to the user [17].

24.4 Recommending Home Health Products

iPHR can automatically recommend home health products (HHPs) based on the user's health issues [11, 12, 19]. The main idea of this HHP recommendation function is to use both nursing knowledge and treatment knowledge and to extend the language modeling method [24] in information retrieval to combine and rank HHPs retrieved by multiple queries. During this process, various relevant factors are taken into account.

iPHR uses both nursing knowledge and treatment knowledge to obtain HHP search guide information. For each SCA, a set of phrases is pre-compiled as its HHP search guide information and stored in iPHR's knowledge base. Each such phrase provides one way of retrieving HHPs related to this SCA. For each health issue (e.g., disease, symptom, surgery), a set of HHP search guide phrases is pre-compiled using disease/symptom treatment knowledge and stored in iPHR's knowledge base. These treatment-based HHP search guide phrases can bridge the semantic gap between the literal meaning and the underlying medical meaning of the health issue.

< Medical Supplies & Equipment
< **Daily Living Aids**
* Bath & Body Aids (797)
* Low Vision Aids (633)
* Medication Aids (178)
* Ramps (157)
* Low Strength Aids (137)
* Eating & Drinking Aids (77)
* Dressing Aids (42)
* Hearing Aids (28)
* Telephones (27)
* Hearing Aid Accessories (12)
* Others (46)

Figure 24.4 A sample navigation hierarchy constructed for the health issue ataxia.

At a high level, iPHR's HHP recommendation function works in the following way. iPHR automatically extracts from PHR the user's current health issues and uses the linkage method described in Section 24.3 to find all of their linked SCAs. Combining together the HHP search guide information for these SCAs and the treatment-based HHP search guide phrases pre-compiled for these health issues, we obtain the complete set of search guide information. iPHR submits each search guide phrase in this set as a query to a vertical search engine to retrieve relevant HHPs. Then all retrieved HHPs are combined together and returned to the user through a navigation interface. On each search result Web page, a navigation hierarchy based on product categories is displayed on the left side as shown in Figure 24.4. Recommended HHPs are displayed sequentially on the right side.

For example, as shown in Figure 24.3, the health issue ataxia (cannot coordinate muscle movement) links to the following SCAs:

(1) Provide sturdy, nonslip *step stools* to facilitate easy reaches;

(2) Provide *nightlight* at bedside; and

(3) Provide visible *handrails* and *grab bars*.

Step stool, nightlight, handrail, and grab bar are HHPs relevant to ataxia. iPHR can recommend these HHPs to ataxia patients using nursing knowledge. Nevertheless, for both ataxia and its symptoms, it is likely that neither their names nor their treatment methods appear in the Web pages describing these HHPs. Consequently, without resorting to iPHR, the average consumer would encounter difficulty in finding these HHPs on his own.

24.5 Continuous User Monitoring

iPHR can perform continuous user monitoring and proactively push personalized, relevant healthcare information to users whenever their potential need for it is detected [13]. The main idea of this continuous user monitoring function is to combine techniques from multiple computing areas, including expert system, Web search, natural language generation, database trigger, and signal processing, to make iPHR become active.

More specifically, triggers are pre-compiled by healthcare professionals and stored in iPHR's knowledge base. The concept of trigger was originally developed in the database field [23] and is extended here to fit the purpose of our specific iPHR application. Each trigger corresponds to a unique abnormal event that may have a potential health impact. Based on the user's health condition, iPHR automatically determines which triggers will be used. iPHR keeps collecting, processing, and analyzing the user's health data from various sources and detecting abnormal events from it. Whenever a trigger fires signaling the occurrence of an abnormal event, iPHR recognizes that the user needs to be aware of the related, personalized healthcare information and automatically pushes this information to the user.

At trigger compilation time, for each abnormal event, healthcare professionals use their health knowledge to perform the following four actions:

(1) Compile the corresponding trigger;

(2) Compile a template of basic healthcare information related to this abnormal event;

(3) For the content included in this template, mark one or more items that they anticipate some iPHR users would want to know more about; and

(4) For each such marked item, compile a set of phrases that can be used to retrieve its detailed information as its search guide information.

As described below, the continuous user monitoring function uses all of the materials compiled from these four actions.

The solid arrow paths in Figure 24.1 illustrate the overall workflow of continuous user monitoring in iPHR. At a high level, this workflow consists of the following five steps.

In step 1, the user's health data is collected from multiple sources, such as wearable sensors and passive sensors [26]. This data includes both discrete events (e.g., sporadically measured body weight) and continuous time series physiological signals (e.g., electrocardiogram).

In step 2, the user's health data is pre-processed to filter out artifacts. Its essential information is then extracted as various kinds of features.

In step 3, abnormal events are detected from the user's health data using triggers. In iPHR, each trigger corresponds to an abnormal event $E_{abnormal}$ and is of the form

$$\text{Firing condition } C_f \rightarrow \text{Action } A \text{ (triggering event } E_{triggering}\text{, applicable condition } C_a\text{)},$$

meaning that if the applicable condition C_a applies to the user, then the action A will be taken when the triggering event $E_{triggering}$ occurs and the features extracted from the user's health data satisfy the firing condition C_f describing the abnormal event $E_{abnormal}$.

In step 4, when one or more abnormal events are detected from the user's health data and their corresponding triggers fire, they are collected together and sent to the natural language generation [25] system of iPHR. Based on how the firing conditions of their corresponding triggers are satisfied, iPHR uses their pre-compiled templates of basic healthcare information to generate basic personalized healthcare information related to them and presents this information to the user on a Web page. Moreover, for each item in this basic healthcare information that healthcare professionals mark during trigger compilation time, iPHR automatically adds a hyperlink to this Web page.

In step 5, the user views this Web page. If he is interested in knowing more details about a specific item in this basic healthcare information, he can click the hyperlink of this item. In this case, iPHR will use the search guide information pre-compiled for this item to automatically form one or more queries to retrieve detailed information about this item and then present this retrieved information to the user.

For example, chronic obstructive pulmonary disease (COPD) patients often experience weight loss, an abnormal event that is associated with increased risks of mortality, disability, and handicap. The defining criteria of weight loss are losing >5% weight in the past month or losing >10% weight in the past six months [4]. For a user with COPD, iPHR will automatically monitor his body weight measures. When iPHR detects that he has lost >5% of his weight in the past month, iPHR will present to him the basic personalized healthcare information shown in Figure 24.5.

Significant weight loss is detected, as you have lost >5% of your weight in the past month. This is particularly problematic as you also have COPD.

COPD patients often experience weight loss, which is associated with increased risks of mortality, disability, and handicap.

COPD patients experiencing weight loss may need nutritional therapy. (Click here to view related food and nutritional supplements.) Since weight loss in COPD patients is often accompanied by muscle wasting, nutritional therapy may only be effective if it is combined with anabolic stimuli such as exercise.

Figure 24.5. An example of basic personalized healthcare information provided by iPHR.

For the "nutritional therapy" item in this basic healthcare information, its pre-compiled search guide information contains three phrases: *COPD nutritional therapy*, *COPD nutritional supplement*, and *COPD nutrition*. If the user clicks this item, iPHR will present the following top results retrieved by these phrases as detailed information about this item: (1) nutritional guidelines for people with COPD (http://my.clevelandclinic.org/disorders/chronic_obstructive_pulmonary_disease_copd/hic_nutritional_guidelines_for_people_with_copd.aspx), (2) nutrition and COPD - dietary considerations for better breathing (http://www.todaysdietitian.com/newarchives/td_020909p54.shtml), and (3) nutritional therapy for COPD (http://www.lef.org/protocols/respiratory/copd_01.htm).

24.6 Conclusions

Intelligent personal health record is a new and rapidly moving field. This chapter presents an overview of our iPHR system. As described in [17], there are many open issues in iPHR and much research work is needed to address them to a satisfactory degree. To improve the existing functions of iPHR as well as to add new functions into iPHR, we expect that more computer science technology will be introduced into the PHR domain and more health knowledge will be incorporated into iPHR in the near future. Moreover, we expect that many techniques originally developed for iPHR, possibly after certain domain-specific extensions, could be applied to other domains for the purpose of using domain knowledge to facilitate users to find their desired information.

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