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Mobile cloud-based depression diagnosis using an ontology and a Bayesian network

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HIGHLIGHTS

- Integrating Ontology with Bayesian Network to predict getting depressed or not.
- Using mobile agent and cloud environment to implement the diagnosis environment.
- Evaluation result shown the system is feasibility for doing the prediction.

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ABSTRACT

Recently, depression has becomes a widespread disease throughout the world. However, most people are not aware of the possibility of becoming depressed during their daily lives. Therefore, obtaining an accurate diagnosis of depression is an important issue in healthcare. In this study, we built an inference model based on an ontology and a Bayesian network to infer the possibility of becoming depressed, and we implemented a prototype using a mobile agent platform as a proof-of-concept in the mobile cloud. We developed an ontology model based on the terminology used to describe depression and we utilized a Bayesian network to infer the probability of becoming depressed. We also implemented the system using multi-agents to run on the Android platform, thereby demonstrating the feasibility of this method, and we addressed various implementation issues. The results showed that our method may be useful for inferring a diagnosis of depression.

1. Introduction

Depression (or major depressive disorder) is a common illness. According to the World Health Organization (WHO), over 350 million people of all ages suffer from depression around the world [1,2]. In the worst case, a depressed patient will commit suicide [1,2]. To diagnose depression, various questionnaires can be obtained from experts or the Internet, and patient evaluations can be made after completing the form. These questionnaires usually analyze the severity of the symptoms experienced by a patient during the past week and the scaled scores are summed to determine whether the patient is becoming depressed. A disadvantage of these questionnaires is that patients cannot obtain their results instantly to monitor their status. In addition, the questionnaires are designed in a static format, thus it is not easy to add new symptoms related to depression. Furthermore, it is difficult to evaluate whether a person is becoming depressed or not. Many studies have evaluated the diagnosis of depression in the past decade [3,4].

E-health (electronic healthcare) was first proposed in 1999 [5] and it is a general model that facilitates the provision of health information, products, and services, which can be delivered via telecommunications. The concept of e-health [5–9] has been developed and applied in many practical areas. A common solution is to employ sensors with telecommunication capacities, which constantly transmit data observations to a database. Suitable medical experts can check the patient's data instantly, or they can be notified if a patient exhibits critical signs. However, the mood of a patient is difficult to collect using a sensing device. Thus, some changes must be made to the traditional e-health concept to allow the mood states of patients to be recorded anywhere at any

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time. Recently, improvements in sensor and mobile technology, m-health [6,7], and u-health [8] have been proposed, which provide a more convenient way to deliver health information to patients via a mobile device that can be browsed instantly on mobile devices.

The cloud environment [10] provides a highly stable and less expensive service, thus increasing numbers of applications are being built in the cloud [11,12]. The advances in wireless communications mean that not all data need to be stored locally [13] and various data can be obtained via the cloud environment. The cloud also provides computing resources that allow users to execute their own programs. Thus, services can be built and provided to consumers and scientists by exploiting the resources provided by the cloud [14–20]. In addition, as described by Foster [21], the grid provides power to solve deterministic problems and agents provide the brain to solve problems in flexible, uncertain, and dynamic environments.

Therefore, the e-health cloud [9] offers the possibility of easy and ubiquitous access to medical data. A general solution to depression diagnosis is to ask patients to complete questionnaires that ask them about their recent physical and mental state. However, it is difficult to apply depression diagnosis via e-health because asking a patient to complete questionnaires on a frequent basis is not convenient, and the results cannot be sent to a database and checked immediately by medical experts. Thus, it is not possible to notify relevant experts on the fly to give help to a patient who is becoming depressed.

Due to the continuing advance of information technology, increasing numbers of studies are utilizing information technology for the automatic inference of the status of patients and to obtain results [22]. In various research areas, ontology [23] is an important technique for representing the terminology used in certain domains. Information technology can process the user's input automatically, and then infer the results according to the input based on an ontology and related rules. However, this approach can only infer certainties and it cannot infer various possibilities accurately for the uncertainties that are inevitable features of most environments. A Bayesian network (BN) is a probabilistic graphical model that represents the conditional dependencies of each node as a directed acyclic graph (DAG). Each node in the DAG has a random probability, where every directed edge represents the dependency between nodes. BNs have been applied to risk analysis in some medical areas [24–26,14].

Merging an ontology with a BN to infer uncertainty is a popular approach in various domains [27–30]. Ontologies can specify a shared conceptualization in a formal and explicit manner. They can provide excellent representations of the organizational structure of large complex domains, where Bayesian probability allows the assignment of probabilities to other types of statement. These techniques have also been applied widely in expert medical systems [24,31,25,26] in recent years. However, they have never been applied to the diagnosis of depression.

In this study, we developed a mobile cloud-based depression diagnosis framework, which we implemented to run on a mobile device. This framework uses an ontology to define the terminology of depression and a BN is employed to infer the probability of becoming depressed. First, we built a depression ontology using Protégé,[1] which is a free and open source ontology editor that allows the explicit representation of the relationships of the symptoms of depression, and it uses the Graphical Network Interface (GeNIe) and Structural Modeling, Inference, and Learning Engine (SMILE)[2] as a BN inference engine. Both run in the backend cloud environment. In addition, at the front end of the mobile cloud, a mobile agent platform is deployed on the patient's mobile device to collect and transmit health information to the backend cloud platform. Users can input their personal feelings into the mobile device. The user agent then sends these inputs to the backend cloud environment to infer the possibility of becoming depressed. A prototype of this framework was also implemented to demonstrate the feasibility of the proposed method. Our results indicate that this method can be an effective and efficient tool for inferring the diagnosis of depression.

This study makes three major contributions compared with previous methods.

- A mobile cloud-based depression diagnosis framework was developed to evaluate whether a person is becoming depressed.
- No previous methods have used an ontology and a BN for the diagnosis of depression. Thus, we constructed a depression ontology model (DOM), which we integrated with the BN technique to build a model to infer the possibility of becoming depressed.
- We used mobile agent technology to implement a readily accessible interface on a mobile device to evaluate the likelihood of becoming depressed anytime and anywhere.

The remainder of this paper is organized as follows. In Section 2, we provide some background knowledge and discuss related research. Section 3 mainly describes the construction of the proposed DOM using Web Ontology Language-Description Logics (OWL-DL). Section 4 shows how the probability of becoming depressed is inferred using the BN technique. Section 5 addresses the implementation issues encountered when utilizing the techniques. Finally, we provide our concluding remarks and suggest future work in Section 6.

2. Background and related work

In this section, we discuss the background of this study and related research. In Section 2.1, we present a preliminary description of the ontology and the BN. A definition of mobile and ubiquitous healthcare is provided in Section 2.2. Finally, previous research related to our proposed approach is discussed in Section 2.3.

2.1. Preliminaries

The concept of an ontology [32,33] is derived from philosophy. In computer science, an ontology is a formal representation of knowledge as a set of concepts within a domain, and the relationships between pairs of concepts. Ontologies are one of the most widely used approaches for enabling system intelligence and for improving the capacity to automate a system by obtaining the system's semantics [34–37]. An ontology may take a various forms, but it must include a vocabulary of terms and specifications of their meaning. In general, an ontology is the manifestation of a shared understanding of a domain, which has been agreed by a numbers of parties.

Different ontology languages have various specific characteristics. The most recent development in standard ontology languages is OWL,[3] which is endorsed by the World Wide Web consortium (W3C) to promote the Semantic Web Vision. OWL provides a language with a rich vocabulary for describing properties and classes, including the relations between classes, cardinality, equality, rich typing of properties, the characteristics of properties, and enumerated classes. An OWL ontology comprises *Individuals*, *Properties*,

[1] The Protégé Ontology Editor and Knowledge Acquisition System, see http://protege.stanford.edu/.

[2] GeNIe and SMILE were developed by the Decision Systems Laboratory, University of Pittsburgh, and they are available at http://genie.sis.pitt.edu/.

[3] http://www.w3.org/TR/2004/REC-owl-features-20040210/.