Ubiquitous Diagnosis: Assurance through Distribution and Collaboration

Daniel Ruiz, *Member, IEEE*, Antonio Soriano, Carlos A. Montejo, Anibal Bueno

***Abstract*— Diagnosis is an important process in patient care. A suitable diagnosis helps a physician determine a precise treatment. Physicians also have a tendency to seek collaboration from other colleagues and expert systems for better confidence in their decision. The sources of knowledge can be both human in the form of medical specialist, and artificial in the form of expert systems connected through Internet, thereby producing a network of distributed medical knowledge. A system that combines availability, cooperation and harmonization of all contributions in a diagnosis process will bring more confidence in healthcare for the physicians.**

***Index Terms*— Distributed knowledge, medical diagnosis, medical expert systems, pervasive healthcare applications, telemedicine.**

I. Introduction

THE healthcare sector has been improved substantially through the use of the advances in technology and information systems that have taken place over the last few years. It is important that the systems created with these technologies revolve around the patient and the process of care [1].

One type of health information systems that has grown in popularity the last two decades are the ones that fall under the category of telemedicine.

Telemedicine describes "the application of telecommunications and information technologies to medicine, in order to provide medical services across distances" [2]. Since distance is the main issue in telemedicine, Internet has served as the appropriate platform for deploying all types of telemedicine applications [3]. The development and deployment of these applications can reach good cost-benefit figures if open-source technologies, low cost hardware and Internet connections are used [4][5]. Telemedicine has given birth to many applications that let physicians be virtually standing next to the patient. They can be used to review X-rays or any type of digital medical image [6], to monitor all types of vital signs [7], to facilitate cooperation between physicians [8] and even to do surgery at a distance [9]. However, many of them require large investments in expensive medical equipment and information technology infrastructures, the immediate presence of the physician, and they usually bring the physician closer to the patient as opposed of bringing physicians closer to physicians.

In a hypothetical case, an elderly patient who lives in a rural area too distant from any metropolitan area goes to the only physician available close-by for a routine check-up. The physician, after checking the patient, suspects of an illness, but he needs the opinion of a specialist in order to provide an exact diagnosis. The next best decision would be to transfer the patient to a better-equipped clinic located in a bigger city, hundreds of miles away, but the patient has neither the strength nor the resources to make such a trip. The physician has the necessary equipment to obtain some initial relevant medical data and images, but he lacks the presence of a qualified specialist. He can use a probably available Internet connection and use a communication mechanism like e-mail, web-based discussion forums, instant messaging software [10], or even something simpler like a phone call to forward the information to a specialist, but there are no guaranties that the specialist is immediately available for consultation.

This example is just one of many where the inconvenience is not the geographical distance between the physician and the patient, but the lack of essential communication between physicians and the lack of any type of specialized medical knowledge. The absence of collaboration among specialists can lead to the delay of medical attention or the precipitated application of an unclear medical treatment in a highly probable emergency.

II. System Objectives and Specification

The main objective of this work is to provide a framework for the remote and distributed interaction and cooperation of expert entities (human and artificial) in medical diagnosis. This cooperative approach will let a physician get a more precise medical diagnosis based on the combination of the individual diagnosis provided. To fulfil this objective we designed a system based on a distributed network of knowledge. In the development of this network, we can find groups of human experts and, furthermore, we use techniques of artificial intelligence in order to complement the diagnosis activity of the human experts. This system is primarily a tool

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D. Ruiz, A. Soriano, C.A. Montejo and A. Bueno are with the Department of Information Technology and Computing, University of Alicante, 03690 San Vicente del Raspeig, Alicante, Spain (e-mail: druiz@dtic.ua.es; soriano@dtic.ua.es; cmontejo@dtic.ua.es; aba11@alu.ua.es).

for physicians. It sets up a collaborative environment in order to control and follow up a medical session celebrated in a medical office, clinic, hospital, or better yet, the residence of a patient.

Other objectives taken into account in the development of the system are:

- Ensure continuous availability of the user interface and the diagnosis process.
- Develop an accessible user interface taking into account user experience and disabilities.
- Fill a medical database for future support of an electronic health record and demographic studies.
- Use open-source technologies and frameworks for reduced costs in development.
- Comply with international public standards and recommendations for future interoperability with other healthcare systems.

A highly available network of medical knowledge has to use artificial intelligence techniques like the ones used in any decision support system. Artificial entities can run on dedicated computer servers and ad-hoc electronic devices connected to Internet, thus ensuring an immediate response.

To attend these requirements, the system is made of the following components:

A. *Artificial Entities*

The artificial entities are software programs or hardware devices in charge of providing a medical diagnosis depending on the input of quantitative and qualitative medical data. The detail of their implementation is transparent to the system. They only need to be connected to Internet at all times, to be able to receive medical data in standardized format, to provide a diagnosis, and to communicate all results to a centralized component called the System Core, described later in this section.

B. *Human Entities*

Human entities are physicians specialized in a certain medical field. From the perspective of the system, human entities behave like artificial entities: they must be able to receive and understand some quantitative and qualitative medical data and provide a diagnosis through a user interface. Human entities are required to have basic knowledge of using any device capable of displaying the web interface like a personal computer, a personal digital assistant or a mobile phone (all with Internet access). Basic knowledge of Internet browsing, webpage navigation and web form submission is also required.

C. *Web Interface*

The web interface is the main point of user access that the system provides for the human entities. It lets physicians submit medical data to request a diagnosis, revise medical data to provide a diagnosis, and review the unique diagnosis derived from all diagnosis. It also includes other interaction mechanisms like news, meetings, articles and announcements.

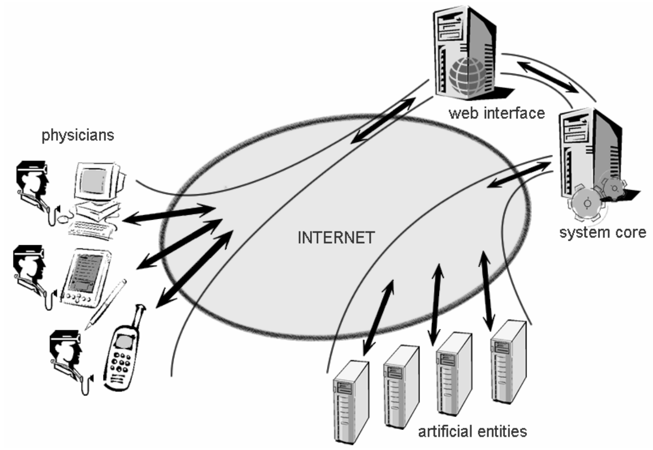

Fig. 1. Distribution of the components in the system for cooperative diagnosis.

The interface distinguishes between physicians, patients and visitors, showing them only the information that is relevant to each group. It is accessible from any device connected to the Internet that is capable of displaying standard web pages.

D. *System Core*

The system core is in charge of managing the list of entities that compose the entire system and the information flow from and to them. It is also in charge of merging all the individual diagnosis returned by all the entities in order to determine a unique one. The decision process of generating a unique diagnosis depends on parameters like years of experience in the case of human entities, and percentage of accuracy in the case of artificial entities, among some others. The process followed by the system core is stored and later reviewed by physicians, thus, refining the diagnosis.

III. Design and Implementation

This section describes the design and implementation of each component necessary in the system. The diagnosis process starts when a medical specialist uses the web interface to request a diagnosis to the system core which forwards the medical data to all diagnosis entities. The artificial entities receive the information directly from the system core, analyze it and return a diagnosis to the system core. The human entities use the web interface to do the same. The system core gathers the diagnosis from all entities and later decides which of them is the most likely to be correct. The final decision is then forwarded to the medical specialist that initially requested the diagnosis. Fig. 1 shows the interaction among these components.

A. *Artificial Entities*

The design of the artificial entities may vary depending on the technique used to find a diagnosis. An example can be the use of an artificial neural network based on a multi-layer perceptron that can diagnose a series of diseases of the lower urinary tract [11]. The inputs of the perceptron correspond to urological measurements and the outputs correspond to possible dysfunctions of the lower urinary tract. Another example is the diagnosis of breast cancer based on a Bayesian network topology of state-aware nodes [12]. A Bayesian analysis of all states throws the probability of the presence of breast cancer in a patient. Other techniques include fuzzy-logic [13] and software agents [14].

The interface of the artificial entities must function as a web service. They must be able to receive and send diagnosis requests and responses in XML format according to the Reference Information Model (RIM) of the HL7 version 3 specification [15]. The artificial entities secure the messages they send and receive with the XML-Encryption specification of the World Wide Web Consortium (W3C). They also sign and validate the messages with the XML-Signature specification, also of the W3C.

B. Web Interface

The web interface is accessed not only by physicians, but by patients and visitors as well who may be interested in the benefits provided by the system. For this reason, the site includes news, forums, announcements, articles, medical studies or questionnaires, and the main diagnosis section used by physicians. The web interface manages authentication with a user-password combination and authorization with a common Role Based Access Control implementation.

We implemented the web interface using the XHTML 1.0 recommendation of the W3C, widely adopted by numerous web browsers in different devices. The use of images and graphical plug-ins is restricted for widespread compatibility.

Since the website targets any type of user, especially without experience and maybe disabled, the implementation follows the Web Content Accessibility Guidelines of the Web Accessibility Initiative of the W3C.

We implemented the website on the freeware Java platform. The website runs on Apache Tomcat, an open-source servlet and Java Server Pages container capable of running on most of the popular operating systems like Windows and Linux. The final layout of the web interface can be seen in Fig. 2.

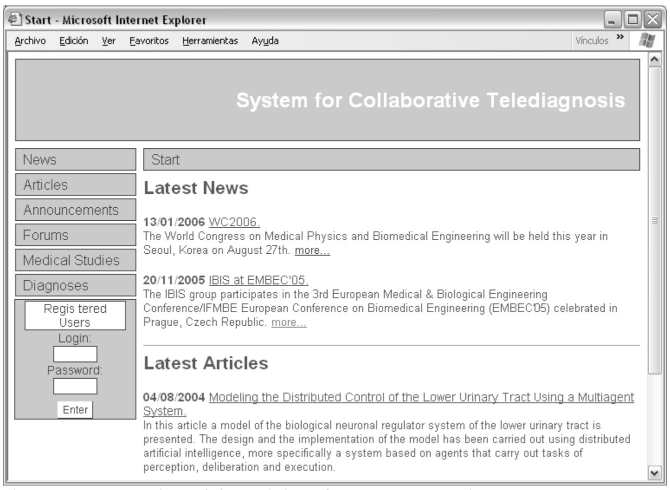

Fig. 2. Representation of the web interface on a personal computer.

C. System Core

The system core is in charge of managing everything related to the diagnosis process, including storage, retrieval and consolidation of the individual diagnosis of all entities. The decision process followed in the consolidation is described later in this section.

The system core stores medical data gathered from all the diagnosis requests. We chose the open-source MySQL relational database for storage and management of this information. The structure of the information follows storage and security parameters recommended and required by public standards and local law (Electronic Health Record, data encryption, access logs, etc).

The artificial entities work as web services, so the system uses the Hyper Text Transfer Protocol (HTTP) and the Simple Object Access Protocol (SOAP) in order to communicate with them. The system also uses the Secure Socket Layer (SSL) protocol for privacy.

After the system core forwards a diagnosis request to all entities, it gathers a series of diagnosis responses and generates a consensus, a unique diagnosis. A decision making scheme is used to determine the correct diagnosis according to parameters like the percentage of accuracy of an artificial entity. The presence of various entities suggests that the decision process should behave like a social or group decision. One of the methods of group-decision is voting which can be used in an environment made of artificial entities [16]. Each entity casts a proportional or weighted vote on a specific diagnosis and the overall count helps determine a unique one. The weighted vote is relative to a percentage, meaning that the maximum weight a vote can have is 100. The weight of the vote of the human entities is the highest for deontological reasons and it is determined in a subjective manner based on the experience and field of expertise of the specialist. The weights of the artificial entities are based on their percentage of accuracy. An example of this voting scheme is described in the following section.

IV. Results

The results shown in this section are based on a preliminary release of the system. This preliminary release includes the implementation of the entire web interface, the development of the decision process, and the implementation of three initial artificial entities (P1, P2 and P3) based on multilayered perceptrons which are capable of diagnosing five different dysfunctions of the lower urinary tract, detailed in Table I [11].

TABLE I
Dysfunctions of the Lower Urinary Tract

ID	Diagnosis
DG1	Areflexia
DG2	Obstructive dysfunction
DG3	Hyperreflexia
DG4	Effort incontinence
DG5	Vesical instability

The diagnosis processes executed by the artificial entities are independent of each other, meaning that we trained them with different separate data. We tested each perceptron with 134 different patterns of urological measurements. For each pattern we knew the correct diagnosis, so Fig. 3 shows the percentage of accuracy of each perceptron on each diagnosis. The entities show a better accuracy (above 60%) for most of the diagnosis studied.

Since the process of selecting a diagnosis among any number of physicians is similar to a voting scheme, we developed a decision method based on proportional voting to determine the "winning" diagnosis. For example, if P1 diagnoses DG2, then 64 votes are granted to that diagnosis, since the percentage of accuracy is 64%. The system adds the votes of each entity and each diagnosis, and the one with the most votes is determined to be the consensus. If a tie appears, no unique diagnose is generated, and the consensus is a combination of diagnosis. This voting scheme is used for both artificial and human entities, and will prove useful when the number of entities is increased significantly.

We tested this voting scheme with another set of patterns in order determine the accuracy of the combined diagnosis or consensus. Fig. 3 shows the comparison of the percentages of accuracy of the individual diagnosis and the consensus (CS). It shows that for most diagnosis (DG1, DG2, DG3 and DG4), the consensus is more accurate than the individual diagnosis of the perceptrons with percentages over 80% on three of the diagnosis. Although DG5 was the exception, the consensus was only less accurate than one perceptron (P1), but was more accurate than the other two.

V. Conclusions

The distribution of knowledge is a powerful tool in a decision support system. By adapting the system to a distributed architecture, any number of future sources of knowledge could be integrated into the network, generating an expanding knowledge-base. In addition, different knowledge sources specialized in the same problem can provide different points of view, a key factor in decision support.

The use of open-source technologies cuts down the costs of implementation significantly, and the use of public standards will let other standardized health information systems use the services provided by the network of knowledge.

By using a web interface, physicians can access the system from any Internet-enabled device with a web browser, and the artificial entities can immediately provide an initial diagnosis in case a medical specialist is not available.

Finally, the combination of different perspectives in a diagnosis adds more precision and more confidence for the physician and the patient. A consensus of all diagnosis can be reached with a voting model, making it a proper decision algorithm to be used in medical diagnosis.

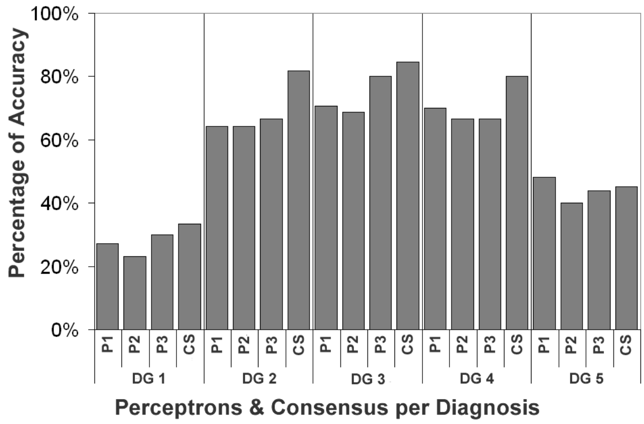

Fig. 3. Comparison of the percentages of accuracy of each of the artificial entities (P1, P2 and P3) and the consensus (CS) on each diagnosis (DG1, DG2, DG3, DG4 and DG5).

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