USING DYNAMIC PUPILLOMETRY INTO A DISTRIBUTED HEALTHCARE SYSTEM

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Abstract – Reducing the complexity of diagnostic systems and methods allows a larger number of medical centers, mainly those in small cities and in isolated regions, due to the easy of use and the smaller complexity for adoption. On the other hand, centralizing the database and diagnostic evaluation of the results allows for traditional and newly diagnostic methods to be applied analyzing a larger set of patients and clinical conditions that can lead to new clinical findings. While dynamic pupillometry has been proposed as a simpler and more sensitive tool to detect subclinical autonomic dysfunction, this paper proposes using it integrate to a distributed medical healthcare system that integrates several small modules via internet, while allowing enabling medical centers to have access to data acquired in that distributed manner with the potential to apply advanced diagnostic methods.

Keywords – Dynamic pupillometry, distributed healthcare system, autonomic nervous system.

1 Introduction

According to the literature, detecting diseases and conditions in their first stages boost the possibility for treatment and healing for the patients [1], [2]. Because of these, much of the effort done lately into the medical area is being directed to the diagnostics area.

As the diagnostic medicine evolves, it is necessary to go beyond the normal symptoms that can be described by the patients and/or detected by the physicians with simple exams. Very specific body parameters need to be measured, analyzed and compared with existing models or parameters. For example, the use of dynamic pupillometry and spectral analysis of heart rate variability for the detection of autonomic neuropathy in diabetic patients [3], [4].

Even assuming small sampling rates, measuring one or more body parameters normally results into an overwhelming amount of acquired data to be easily analyzed by physicians, nurses, pharmacists and other healthcare professionals during the diagnostic process unless an automated computing process is adopted for separating the clinically significant data. Additionally, healthcare systems have difficulties in managing personal data, standardizing the data, extracting content-based knowledge and storing this information into databases. These problems indicate the need to improve the quality of healthcare systems, to ease the access to healthcare and healthcare information, and to reduce the cost of delivery of healthcare [5].

During the studies of new diagnostic methods it is necessary to compare the new parameters and data against known and already accepted methods and parameters, so it is possible to determine the effectiveness of such a method in detecting a condition [2]. This is not always easy, as studies involving human subjects have to rely on very tight regulations. Having a unique database of several different parameters and diagnostics collected could provide valuable knowledge. Moreover, researchers may follow a systematic approach and evidence-based methodology during the development of new clinical preventive methods [2].

Limitations and challenges while developing process oriented architecture for an integrated healthcare network are flexibility, adaptability, robustness, integration of existing systems and standards, semantic compatibility, security and process orientation [6].

In this paper, we describe a dynamic pupillometry system that we have been developing. Our system works integrated into a distributed healthcare system named e-Health System. This distributed system was developed for easy scalability, allowing the number of diagnostic methods, medical centers, patients and tests to grow with minimum effort. To achieve this, most of the system is held into centralized datacenters (in number of one or more, depending on how large the system grows), thus removing unnecessary complexity from the diagnostic algorithms, especially when we are talking about medical centers with limited infra-structure.

2 e-Health System

e-Health System is a distributed healthcare system that has been developed as a partnership between Federal University of Paraná and Federal University of Santa Catarina. Its initial application is the evaluation of autonomic neuropathies, mostly caused by diabetes. Two diagnostic methods were considered during the first phases of the project: pupil stimulation response measuring, via dynamic pupillometry, and heart rate variability analysis, via recording processing and analysis of the electrocardiogram.

The architecture of the e-Health System is divided into four module types that will be described below. These modules communicate themselves by using a designed Application Programming Interface (API). All the methods from this API run over XML and HTTP technology, using Web Services technology [7]. A simplified view of the architecture of the system is shown in Figure 1.

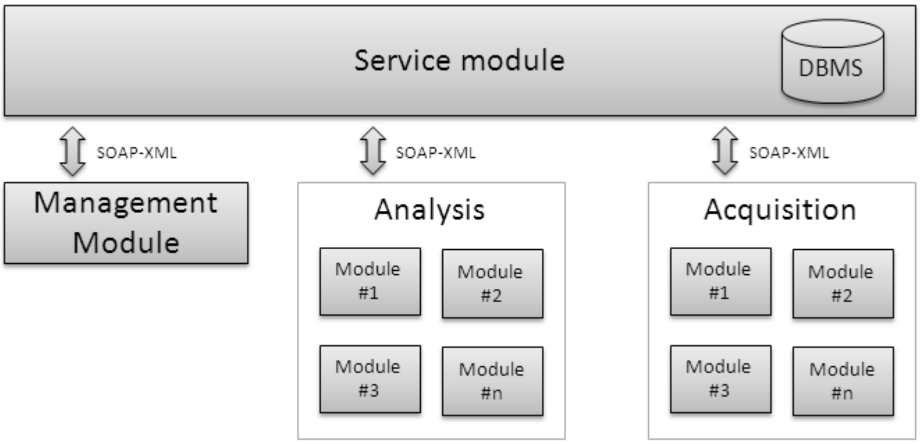

Figure 1 – e-Health System basic architecture

Service Module

Although most of the system is designed to run into a distributed way, there is the need of having one central service module that should be contacted by the other modules. This service module provides a pre-defined set of web services, each one with the necessary collection of functions so the modules can read and write the necessary data at the system.

The service module is also responsible to control the storage of all necessary data generated by the system and its modules. To relieve the developer from most of relational-data persistence-related developing tasks, e-Health System uses NHibernate, which is an open source component that provides Object-relational mapping (ORM) technology for the .NET platform. By using these kind of technology, it is possible a later migration of all data to another database without much effort. The database used by the e-Health System at the given moment is PostgreSQL.

The following web services are available to be used by other modules:

- User Service: the access to the system is available for several users. These users can be physicians, nurses, pharmacists and other healthcare professionals. Each one of them has a login and password and is assigned to a specific location, which normally is the medical center where it acts. Also, each user has a very specific set of permissions, to control his ability to read and/or write another users data, locations, patients, modules or exams. This is necessary to ensure security and privacy, which are particularly important issues in healthcare activities [2]. All the necessary functions that control these user-specific functionalities are held inside a named User Service.

- Location Service: each user is assigned to a specific location, which can be any location where some module is used. Mostly, these are medical centers, hospitals and similar, but not only, as any place that has the necessary hardware to analyze the data gathered by acquisition modules (see below) is named a location. To control all location-related functions, which mostly is creating, removing or renaming locations, there is a specific web service named Location Service.

- Patient Service: every exam done using the system, no matter of what type, should be assigned to a patient. This way, it is possible to trace the evolution of a condition and check results of multiple exams. Due to privacy reasons, patients should not be identified by their name, but by a code or identification string and will be assigned to a primary location, which normally will be the medical center he is registered. All the necessary functions to control the patients inside the system are accessed by a specific web service named Patient Service.

- Exam Service: each set of data gathered using the system, no matter which type of diagnostic is being aimed, is called an "exam". The raw data collected is stored as an exam pending analysis and is relative to one specific patient. A patient may have as many exams as needed so it is possible to use multiple diagnostic approaches and also have a long-term overview of the results. So the specific modules can add the raw data and make the processing of it, making the results available at the system, a web service named Exam Service is accessible for the modules.

- Module Service: as shown in Figure 1, for each type of diagnostic, two module types are necessary: acquisition module and analysis module. Each one will be described later into this paper, but for their operation, a set of functions is necessary. The first set is used to add, remove and configure the modules into the system, granting that only authorized modules will be available. The other set of functions is called by the modules so they can configure themselves to proper operation according to the system parameters, like request delay and timeout, minimum firmware revision needed, etc. All these functionalities are stored inside a web service named Module Service.

Acquisition Module

The idea behind the acquisition modules is reducing its complexity, so it can be easily deployed into decentralized healthcare places. They should have only the necessary hardware for measuring the body parameters, gathering the data and sending these to a remote server responsible for analyzing the data.

An example of acquisition module would be a pupillometry system based into a simple camera, light emitter diodes for illumination, all this connected to a simple computer with internet connection in order to send the data for the remote server [8].

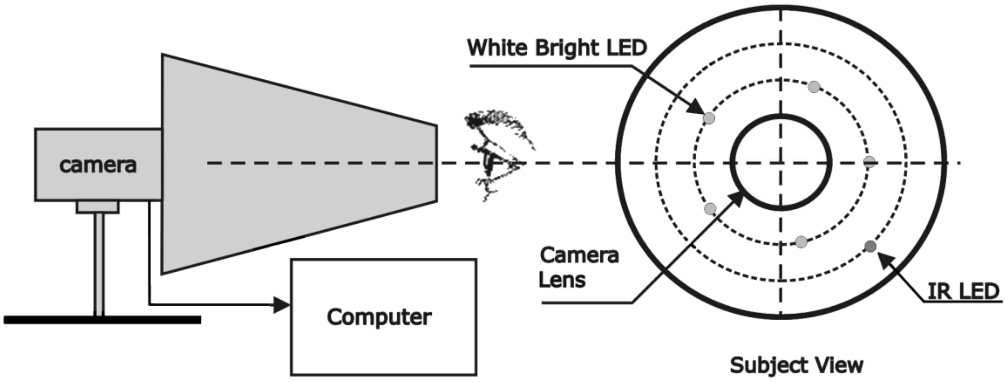

Figure 2 – Pupillometry system. Image modified from [8].

Differently from the service module, that is unique for the whole system, the acquisition modules do not need to be unique. This is necessary in order to allow multiple locations to have access to the same diagnostic approach at the same time. Each location may have its own acquisition module (or even more than one, depending on the demand of diagnostics), all of them contacting the central service module to enable the data analysis and storage. Also, each diagnostic method will have its own need of body parameters measuring needs, resulting in the necessity of having multiple acquisition modules, each one with the necessary sensors and acquisition software for that exam type.

After the necessary data gathering is done, the acquisition module needs to send the raw data to the system, so this data is stored into the centralized database and will became available for proper analysis by some analysis module. The raw data file format is not specified and is sent to the server as a generic array of byte. This way, each diagnostic method can store its data in such a way that best fits its needs. The only requirement is that the analysis module for that diagnostic approach can also understand that format. The exam service provides all the necessary methods for sending the data to the server and should be called by acquisition modules after proper authorization request.

While there is the need for authorization control among the modules, each module has a globally unique identifier (GUID), which is a unique 32-character hexadecimal string that is stored inside the module token. This GUID is compared to a list available inside the service module, to ensure that the module can access the system. Before using any system service, each module needs to request an authorization token via module service. In case of valid authorization, a token and a valid timeframe for that token are informed and should be used by the module for each subsequent request. When the token expires, a new one should be requested.

Analysis Module

For each acquisition module type, it is necessary to have, at least, one analysis module that will be responsible in getting the raw data stored into the main database and does the necessary analysis. The analysis result should be relevant clinical information with the potential of facilitating the diagnostic process done by physicians.

Similarly to the acquisition modules, each analysis module has also its own GUID and should also ask for authorization in order to access the system. One point that differentiates how analysis and acquisition modules handle authentication is that is expected that analysis modules keep running all the time, requesting exams pending for analysis (see next paragraph). Because of this, at most cases, the analysis module will request a new token as soon as the old one expires. During the authorization process, the analysis module will also send and request all necessary configurations to the service module, one example of these configurations is a maximum processing time for the raw data.

After a proper identification and authorization, the analysis module is available to ask for available exams pending analysis. If some exam compatible with the module algorithm is available, the service module assigns that exam to the requester module. After this, the download of the raw data can be done and the analysis process of the data can be started. When the analysis is done, the result is sent to the service module into a XML format, and the exam is marked as processed.

When an exam is assigned for analysis, the results should be sent back to the service module at a maximum period of time equal to the processing timeout that was set during the module authorization process. After that period of time, the exam is available to be reassigned for analysis.

For the proper user exhibition, it is necessary to transform the XML data results generated after the analysis into a user-friendly view. This is done by using XSL transformation language, that is a small set of instructions created to transform XML data into HTML that can be direct shown at any browser. As each analysis module generates its own data format for the results, it is also necessary that the transformation language for that module is available at the server, and this is done also during the authorization process.

Using this architecture, it is possible to have multiple analysis modules doing the same type of processing, this way increasing the processing capability for that type of analysis. The Service Module will assign an exam for each analysis module, in order of request, as they became available. This way, enabling clustering is very easy, and not dependable of high cost hardware and/or software.

Management Module

A single management module is available at the system, so the users can control all the aspects of the system. This management module aggregates all the available operations regarding users, locations, modules, patients and exams. This module is web based and consumes the web services made available by the service module to provide all its functionalities.

As all the necessary functionalities of the system are accessed via the service module web services, having one single management module is not mandatory, so it is possible to have multiple management modules, each one customized by the a specific set of needs and with the possibility of running into separated environments. So far, the initial idea at e-Health System is having one unique management module, enabling or disabling each of the functionalities according to the user permission set.

3 Dynamic Pupillometry at e-Health System

Acquisition Module

The acquisition module was developed using a camera from the manufacturer Basler, mounted together with several LEDs for illumination and stimulation of the subject pupil. For controlling the illumination a small board was done with a PIC microcontroller. This hardware was connected to a computer running the acquisition software by Ethernet (camera) and USB (PIC microcontroller). The software developed is responsible for triggering the camera recording and turning the LEDs on and off automatically. This software was written following the proposed architecture from e-Health System.

When the acquisition is commanded, the software starts the IR LEDs for illumination and starts capturing the images generated by the camera. After a configured time, the stimulation white LEDS are turned on for a specific time. This will make subject pupil reacts and start constricting. The captured frames are stored as an AVI video file, which is sent to e-Health System following its guidelines and using its API. Each frame from this video will be read and processed later.

An overview of the developed pupilometer and the software used for the acquisition can be seen into Figure 3.

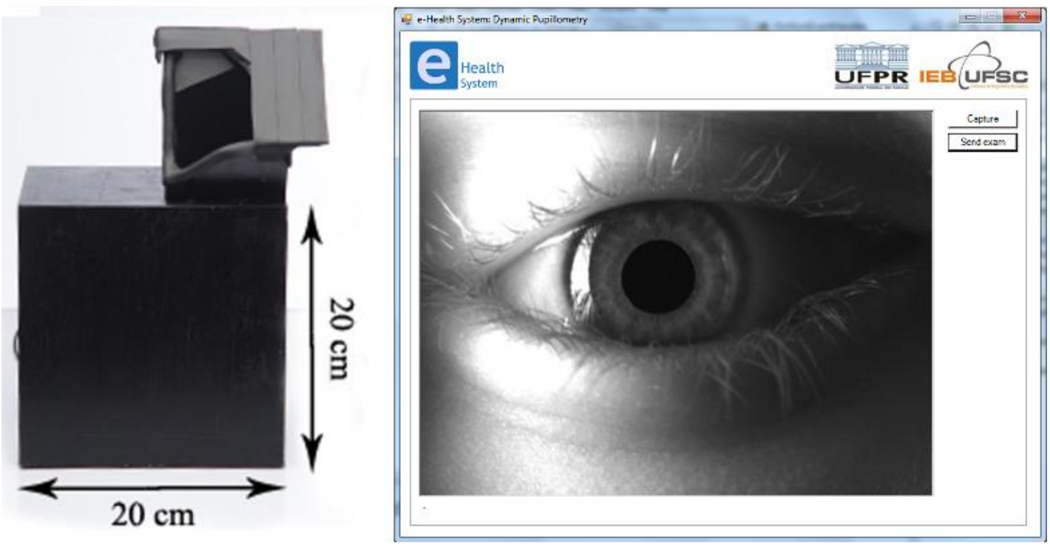

Figure 3 – Dynamic pupillometer – hardware + software overview

Analysis Modules

In order to process the video captured by the acquisition module, an analysis module was also developed. This software uses the available methods and services described in chapter 2 to get the video from the centralized database. After downloading this video, the video is processed, one frame at a time to find the pupil and iris locations and radius.

These results are then shown integrated to the e-Health System, so the medical crew can have an overview of the pupil reaction to the stimulation over the time, including time and size parameters. An example of this overview is shown into a graphical format as show in Figure 4.

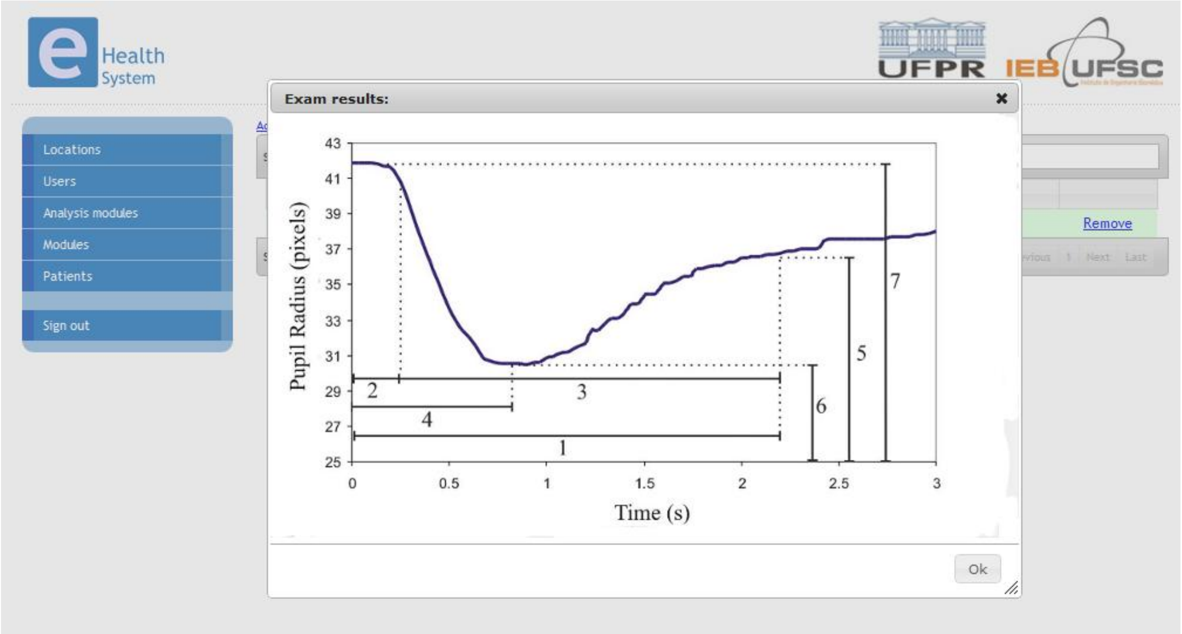

Figure 4 – Autonomic function testing results via dynamic pupillometry

4 Conclusions

When talking about countries with continental-sized territories, especially those still in development process, actions that help minimizing the distance frontiers and limited funding are very important. While talking about medical care, this can be done creating ways to allow people to have access to modern diagnostic approaches even when they don't have access to large hospitals or medical centers.

The e-Health System aims allowing small medical centers to have access to a large number of new exams and tests without much investment in expensive hardware, only being necessary to buy the acquisition modules and simple computers with internet access. The centralized database of the system helps minimizing geographical limitations for the physicians, enabling them to check patient data, tests results and diseases progress anywhere. Also, gathering a huge number of statistics about diseases, including its evolution and appearing against subject gender, age and geographical location is also possible with this healthcare system. The existence of a this database of the raw data collected into the medical centers make possible for new diagnostic methods to be developed and tested against existing data taken by using other methods.

e-Health System was developed to work in such a distributed system, so it can be used for a very large number of diagnostic algorithms and methods without changes to the core of the system. It is only necessary to develop the modules following the proposed workflow and they can operate with the system, aggregating new functionalities for the physicians. Its semi-decentralized and adaptive architecture described in this text allows the whole system to grow from a single tool to a complete suite of tools that can help in the diagnostic of diseases and conditions. The fact that each module can be run in separated machines and the possibility of having multiple modules with the same function enable the whole system to be scaled without the need of dedicated clusters for parallel processing.

Dynamic pupillometry provides a simple, inexpensive, and noninvasive tool to screen high-risk diabetic patients for diabetic autonomic neuropathy. This fits perfectly with the idea of the e-Health System, which is to reduce costs and provide inexpensive tools to improve healthcare systems provided to users into medical care centers.

5 References

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