EcoCloud: A Specialized Computer System for Elaboration Echocardiography Reports

Completed Research

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Abstract

Understand an echocardiogram and draw its conclusions are complex and time-consuming tasks, which contains specific parts that might be automated. Thus, this paper presents the EcoCloud, a specialized software which aids doctors, through automatic generation of cardiological diagnostics and allows the use of mobile platforms, which provides mobility and agility. This study considered the system architecture, technologies used in its development and its main functionalities, the predefined rules used in the reports generation, and a case study of over one year period. During the case study, our system was used by several doctors in hospitals, clinics, and units of prompt care from Paraná, Brazil. Along this period, the EcoCloud generated a database of 5,008 reports from different patients containing several features. The results demonstrated that system is a viable alternative for cardiologists who wants agility in patient care and assistance in the decision-making process.

Keywords

EcoCloud, Specialized Computer System, Echocardiography Reports.

Introduction

Health information technologies have the purpose of providing better services to hospital organizations. The nature of this sector, which is profoundly influenced by the economy, social factors, politicians, and technology, changed over time. The technology evolution brought to reflection on analog work model and its possible improvement (Sharovsky, 2008). Consequently, computational systems applied to health care have been developed in their capacity and interactivity exponentially and its cost reduced in inverse proportion. Thus, the digital environment in this sector offers many advantages, more specifically, on the issue of the Electronic Medical Report (EMR) (Curcin et al., 2017; Karimi et al., 2015).

The EMR constitutes the core of a computer health system. The electronic storage of clinical information developed a potential, for computational tools, to assist clinicians in improving
the quality of medical care significantly and increasing the efficiency of medical practice (Chaudhry et al., 2006). Furthermore, computer-based systems can generate automated exam reports, and immediately notify clinicians when test results are ready. Thereby, it might increase the time available to plan strategies for a diagnostic that indicate adverse conditions, besides other benefits (Curcin et al., 2017; Sujansky, 1998). Thus, the EMR can improve considerably the way clinical medicine is practiced, on the point of establishing a revolutionary technology in health care (Sujansky, 1998). However, the majority of doctors yet use traditional methods for routine actions, as is the case of the echocardiographic report elaboration (Gottdiener et al., 2004; Pellikka et al., 2007; Picard et al., 2011).

The echocardiogram is a test that uses high-frequency sound waves to make pictures of the heart, which is also called echocardiography or diagnostic cardiac echography (Otto, 2012). This test is used to examine the structure and cardiac performance of the heart. The exam helps to find out the size and shape of the heart, thickness and movement of the heart walls, blood pumping force, evaluation of cardiac valves and other factors. For example, a heart failure (weak and large heart), congenital anomalies and heart attack are monitored through the echocardiogram. The methodologies used to prepare the reports are based on American studies (Gottdiener et al., 2004; Picard et al., 2011). According to American Society of Echocardiography (ASE) (Pellikka et al., 2007; Picard et al., 2011), recommends that all echocardiographic reports follow a uniform presentation pattern and a common language that includes key elements data of cardiac structures and measurements, also presenting laboratory reports similarly in structure and writing.

Nevertheless, several doctors still use manual methods to prepare reports, in which the main problem is data decentralization, where many are elaborated in systems incapable of store information, if inserted in system, but also the lack of standardization (Gottdiener et al., 2004; Pellikka et al., 2007). Therefore, Picard 2011 declares that the electronic elaboration of the report facilitates the adaptation of the recommendations mentioned above. Through technology, systems can be implemented in order to automate some parts of the process. Based on these attributions, we developed a specialized computer system for the elaboration of the echocardiography reports, the EcoCloud, which has the purpose of generating automated diagnostics through parameters predefined by the ASE. This study presents an overview of the EcoCloud’s architecture and the technologies used in its development. Also, we describe the main system functionalities and how they optimize the EMR elaboration, and the specific rules used to determine each diagnostic report. A case study depicts our system use in real exams. Followed by the results aroused by EcoCloud and a discussion with regarding the system impact on the practical elaboration of EMR.

This remaining of this paper outlines as follows: Section 2 discusses the previous works related to our research. Section 3 presents the developed system. Section 4 reports a case study and our results. Finally, Section 5 describes our final considerations and future works.

**Related Works**

The use of Health Care Information Systems is essential for any organization that needs to integrate and centralize patient information (Ferreira et al., 2004). Currently, experts consider the Health Information Technologies (HIT), especially Clinical Information Systems (CIS), efficient ways to obtain quality, patient safety, reduction of medical errors and cost reduction (Reid et al., 2005). Necessarily, the definition of objectives and benefits presented by a CIS are: provide relevant information, establish productivity, improve the innovation process, obtain and disseminate external knowledge and increase the degree of collaboration (Karimi et al., 2015; Curcin et al., 2017). Several systems have been applied in health care, for example: Fight Epidemic (Dengue, Zika and Chikungunya) (Lombardo et al., 2003; Oliveira et al., 2016), Physical Activity (Ritter & Rigo, 2016), Medicine (Bates et al. 2001; Small et al., 2017), Extraction of data in electronic medical reports (Lim et al., 2007; Mason et al., 2017; Payne et al., 2018), Treatment of Diseases (Bitar & Ward, 2016) and clinical decision support (Dwivedi et al., 2017). The use of these digital resources represents an
important instrument to assist professionals in decision-making, prevention, diagnosis and patient monitoring (Sujansky, 1998).

Another essential terminology in HIT is Electronic Medical Records (EMR), which refers to a medical record about a patient in digital format. This system coordinates the storage and information recovery with the aid of computers (Reid et al., 2005). EMR technology involves capturing, storing, recuperating, transmitting and manipulating data related to the patient’s health, including clinical, administrative and biographical data (Almunawar & Anshari, 2012). Furthermore, the EMR generates numerous advantages for organizations to improve the decision-making process: speeding up the access to health history and remote availability; simultaneous use of various services and health professionals; flexibility of data layout; elimination of data redundancy; integration with other information systems; continuous data processing and access to updated knowledge (Barnett, 1989; Sujansky, 1998; Wang et al., 2003).

Based on these statements, the literature presents several proposals. Lim et al. (2007) developed an EMR system to mobile phones. The system extracts a text summary of the medical report and a screen captures the medical diagnostic image in JPEG format, transmitting the file to 3G GSM mobile phones. Three components divide the software: medical image information, message generation, and transmission gateway. Sistrom et al. (2005) proposed a framework for conceptualizing the radiology reporting process and how it should be improved: standard language, a structured format, and consistent content. Basically, the authors modify the clinical reporting process, including the creation, storage, transmission, and review of interpretative documents.

Rector et al. (1993) elaborated a model for an EMR which satisfies the requirements for a reliable and structured record of patient care. The model provides for a permanent, utterly attributable record of patient care and the medical decision-making process. The model separates the record into two levels: direct observations of the patient and meta-statements about the use of observations in decision making and the clinical dialogue. Segal et al. (2001) presented a system to provide a medical record management service, which supports the creation, storage, access, update and distribution of patient medical reports, especially medical images of diagnostic quality.

Nevertheless, at the end of our literature review, we verified that the majority of the works included issues on electronic records for general patient registration, in other words, it has no specific function. There's a lack of research regarding an expert system to aid doctors in the echocardiographic reports elaboration. According to Sharovsky (2008), the echocardiography laboratories is not entirely digital. Doctors yet use traditional methods for routine actions, with low efficiency, due to the various manual steps of the process to elaborate a report.

Furthermore, based in the works of Hevner & Chatterjee (2010) and Peffers et al. (2007), that proposes a methodology for conducting design science (DS) research in information systems, we applied in this article the phases of problem identification and motivation; definition of the objectives for a solution; design and development; and demonstration. However, the phases of evaluation and communication are not in the scope this paper. Therefore, we developed the EcoCloud, which stands out mainly because it is a specialized system for the generation of structured echocardiographic reports. It has the goal to increase the quality and the efficiency of some parts of the traditional process, also providing use of mobile platforms, allowing mobility and agility to doctors (Miller & Sim, 2004).

**EcoCloud**

Supported by the contributions that an information system might exercise, and the need to speed up the process of electronic reports elaboration for an echocardiogram, we present
the EcoCloud\textsuperscript{1}. This system has the purpose to aid doctors, automating the emission of echocardiogram reports through predefined rules. Therefore, it was developed with the collaboration of different cardiologists, over two years, aiming to incorporate their knowledge on the system and automate this medical exam workflow. Figure 1 illustrates the workflow.

![Diagram](Image)

**Figure 1**: Comparison of how the echocardiogram is accomplished using the traditional process and EcoCloud process.

The Figure 1 demonstrates a comparison of how this process is accomplished using the traditional method (manually) in comparison with the proposed method (automatically). In the Traditional Process, first, a reading of heart measurements is performed, consulting on books and support materials to obtain heart conditions and crossover of intervals. Then, the report preparation is done manually, from the patient data until the descriptive report. Therefore, on average, the patient needs to wait a minimum of 48 hours to receive the result. Moreover, patient and heart data are not stored, in other words, medical history is not generated (Gottdiener et al., 2004; Pellikka et al., 2007; Picard et al., 2011).

In the EcoCloud Process, first and foremost is performed the reading of heart measurements and insertion into the system. After that,, the system applies cross-checks in the database and automatically generates the report. At the end of the consultation, the report is available for the patient by e-mail. Notwithstanding, the system generates the patient's medical history. Finally, the rest of this section outlines the system architecture, technologies used in its development, its primary functionalities and how its predefined rules work.

**Architecture System**

For the architecture project was adopted a model based on the following works (Oliveira et al., 2016). This model decomposes the system into three levels: presentation, application, and data. The presentation layer contains the displayed elements to the final users and allows the interaction with the system. The web version was developed using the **Zend Framework** to back-end, **bootstrap** to front-end. The application layer is responsible for the process of the requested operations from the users. It contains all system logic which was developed using **PHP, Objective-C, and Java**. Finally, the data layer is responsible for the

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storage of all data generated and processed by the application layer that is visualized on the presentation layer. For the database management used the open source system MySQL.

**Electronic Report**

The visual presentation of the electronic report is based on four models. A questionnaire answered on the user's first access to the system selects the model. According to the answers, the software suggests a model judged most suitable for the doctor's profile. However, it also enables him to choose another one if he/she prefers. These models are customizable to enhance the user's satisfaction, allowing him/her to alter phrases, measurements intervals and parameters presented on the automatically generated report. Specific predefined rules, described in Section Report Elaboration, generate the conclusion presented in the reports. Thus, the four electronic reports models are the following:

1. **Model A**: Creates a list report. All texts contained in the reports are extracted from a phrase database and are chosen based on the patient's heart parameters, found in the echocardiogram exam. Also, it allows inserting customized text on the comments and diagnostic impressions fields.

2. **Model B**: Contains the same mechanism that the model A. However, this one is recommended to doctors which instead have heart measurements presented in a tabular form.

3. **Model C**: This model, differently from the previous ones, does not automatically creates the report phrases. Instead, it categorizes the report in cavities; thickness; contractility; diastole; valves; pericardium and; aorta, and then the doctor decides the diagnostic text for each one of the categories. He accomplishes that using the text from the system database that best fits the exam results. Nonetheless, it follows the same data presentation strategy than model B (tabular).

4. **Model D**: A model which is very similar to model C. However, the system prepares a full conclusion, based on the information entered by the doctor.

**Report Elaboration**

The EcoCloud performs the following steps to prepare reports. Initially, a user records the patient's information and update his measures. Then, the doctor receives a new patient notification and an updated list of his/her schedules. In sequence, the doctor inserts information regarding heart measurements and valve conditions (mitral, tricuspid, aortic and pulmonary), obtained through the echocardiogram. The ejection fraction is calculated automatically, based on the patient's data and measures received. However, the doctor can insert functions and edit ejection fraction, if necessary. Therefore, based on the measurements inserted by the doctor; the system includes in the report a list of observations, by means of predefined values (i.e. pericardium situation). Finally, the system attaches the echocardiogram images to the report and changes its status to finished.

In addition, the observations and diagnostic impressions are automatically generated by the system, using predefined measurements of the American Society of Echocardiography (Gottdiener et al., 2004; Picard et al., 2011). Note that these measurements are generated based on several patient's information (gender, weight, height, age, heart measurements, dilation of atria and ventricles, ejection fraction calculations, stenosis values, calcification, reflux, signaling use of biological or mechanical prosthesis and segmental contractility) in order to find the correct diagnostic.

This information is inserted by a user (commonly the doctor's secretary), during the patient registration (e.g. birth and sex data) and during the echocardiogram (e.g. aortic root and left atrium), besides who is the doctor responsible for the exam. The references used to define the diagnostics were based on (Gottdiener et al., 2004; Picard et al., 2011) and we exemplified in Figure 2 the rules for the left atrium.
As can be seen in the Figure 2, the system follows a number of rules, which are defined according to the patient’s gender. For both male and female, the Left Atrium has four intervals. Following the example presented in Figure 2, a male patient as a Left Atrium of 38mm is diagnosed with a Left atrium with normal anteroposterior diameter. As a second example, if the system were to consider a female patient, with a left atrium of 49mm, the report would display Left Atrium with moderate increase of anteroposterior diameter.

**EcoCloud: A Case Study**

After one year of development, the EcoCloud was deployed for a test period in hospitals, clinics, and units of prompt care from Paraná, Brazil. During one year, until the point of the submission of this paper, many tests have been conducted. Several doctors used the system for the examination of real patients, providing feedback about the software performance to its developers. However, during most part of this first year, the EcoCloud was used with a double check. Meaning that, besides the software, doctors also used their preferred way to perform the diagnosis, aiming to detect possible inaccuracies on the system reports. Based on the testimony of one of the doctors who use the system, the optimization of the reports is strongly cited since the anthropometric data of the patient are previously registered by the doctor’s secretary, different from the traditional process without the use of the system. With these anthropometric data, the system automatically calculates some values necessary for the diagnostic impression of the report, such as ejection fraction, mass index, and relative thickness.

Using the system, a total of thirteen examinations were performed at a two-hour interval, with an average of ten minutes each. In each consultation, there is the initial and final conversation with the patient. Considering this, the report takes on average two to three minutes to be made. Through the advantages that the system offers in relation to time optimization, doctors say they perceive the improvement in their quality of life, as well as opportunities for other activities out of work and greater revenue due to the possibility of a greater number of daily consultations.
This test period generated a database of 5,008 reports, considering its four models (see Section Electronic Report), where models A and B (automated models) were used the most (4,932), whereas models C and D had originated only 73 and 3 reports, respectively. The remaining of this section will present the information obtained from the automated models only, due to the small number of reports available from the other ones and, finally, we will point out the current situation of the EcoCloud's application at the point that we wrote this paper. The sample (4,932 reports in Model A and B) examined with the help of the automated models were close to an equal distribution, between males and females, with 47% and 53%, respectively. On average, they had 55 years, a 27.56 Body Mass Index (BMI) and a body surface of 1.86. Figure 3 demonstrates the percentage of exams performed by age intervals.

According to the graph, the majority of patients (39.92%) had between 51 and 70 years. In contrast, the minority (10.50%) carried a range less than or equal to 30 years. The remainder had between 31 and 50 (27.88%) and were greater or equal to 71 (21.70%) years. For a better analysis of these group of patients, the paper presents the BMI according to each age group.

![Figure 3: Percentage of patients grouped by age(years).](image)

The BMI guidelines (Garrouste et al., 2004; Hsu et al., 2006) covers 5 categories: normal weight (18.5 to 24.9 kg/m²), overweight (25.0 to 29.9 kg/m²), class I obesity (30.0 to 34.9 kg/m²), class II obesity (35.0 to 39.9 kg/m²), extreme obesity (>=40 kg/m²). Consequently, all age groups exposed are overweight. The group of 31 to 50 and 51 to 70, presents the highest rates of BMI, 28.11 kg/m² and 28.29 kg/m², in proper order. Moreover, using the others information collected by the system (see Section Report Elaboration), we were able to find relevant data, concerning heart’s health, such as the Ejection Fraction (EF) of Teichholz. According to Arora et al. (2010), the left ventricular ejection fraction (LVEF), calculated by the formula Teichholz, is important for characterization and management of patients and selection of therapy. In our case study period, our population had a mean of 0.58 for the EF of Teichholz.

This metric provides the evaluation of left ventricular ejection fraction (LVEF), which is an essential component in the understanding of any heart disease (Mueller et al., 1991). Nonetheless, in Table 1, other features collected during this period are displayed, now divided between male and female genders.
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Male</th>
<th>Female</th>
<th>Parameter</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>54</td>
<td>56</td>
<td>Left Atrium (mm)</td>
<td>37.65</td>
<td>35.33</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>82.33</td>
<td>70.14</td>
<td>Interventricular Septum (mm)</td>
<td>10.30</td>
<td>9.52</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.72</td>
<td>1.60</td>
<td>Rear Wall (mm)</td>
<td>9.49</td>
<td>8.73</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>27.69</td>
<td>27.43</td>
<td>Diastolic Diameter (mm)</td>
<td>47.41</td>
<td>43.98</td>
</tr>
<tr>
<td>Body Surface (m$^2$)</td>
<td>1.97</td>
<td>1.76</td>
<td>Systolic Diameter (mm)</td>
<td>30.05</td>
<td>27.89</td>
</tr>
<tr>
<td>Aortic root (mm)</td>
<td>33.76</td>
<td>30.24</td>
<td>Ejection fraction (Teichholz %)</td>
<td>0.56</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Table 1. Data Acquired in Model A and B - Averages of Male and Female Patients.

The table compares, for 12 features of patients (4,932 reports), the average of the results between male and female genders. These data were extracted from echocardiographic examination and are essential for the analysis of heart diseases. It allows us to identify that men and women had similar BMI indexes, whereas other features, such as Aortic root, Left Atrium, and Diastolic Diameter, had higher values for the men. In summary, this case study demonstrated that the EcoCloud enabled the generation of a medical database, containing several measures, which allows various analysis similar to the ones that we demonstrated. However, discussing these health results is not the scope of this paper. Therefore, during this period, the system proved to be a reliable tool for reports generation, having its automated models used predominantly and being used the most without the double-check process.

Conclusions and Future Works

Understand an echocardiogram and draw this exam’s conclusions is a complicated and time-consuming task, which contain specific parts that might be automated. Thus, we presented the EcoCloud, a software which aids doctors through the automatic generation of specifics diagnostic. The system uses a phrase database and a set of predefined rules which, based on the echocardiogram data, creates exam reports. This information is real-time generated, requiring only the filling of parameters identified by the echocardiogram during the exam procedure. Also, we demonstrated the software’s architecture, its main modules and how it presents and generates the reports.

Notwithstanding, we described a case study of over one year and analyzed the database. During the case study, our system was used by several doctors, in some hospitals, clinics, and units of prompt care from Paraná, Brazil. In which generated a database of 5,008 reports from different patients containing numerous features. This process enabled us to perform critical corrections on the system, which resulted in most of its users quitting the use of double check and choosing to use the automated report’s models.

Nonetheless, we conclude that the EcoCloud is a viable alternative for cardiologists who wants agility in patient care and assistance in the decision-making process. In some years, after using the platform in other parts of Brazil, the expectation is to develop a Brazilian patient database, considering social variations, such as ethnicity, culture and regional habits. Nonetheless, a limitation of this research was that we only presented the process of tool
construction, whereas a complete assessment, including the system's evaluation and communication, is our next research direction.

REFERENCES


