Proposal of a Context-sensitive ECG Collection Mobile Health System for Ambulatory Cardiovascular Diseases

Cristian Moreno-De La Cruz¹, Miguel Vargas-Lombardo²

¹Maestría de Ciencias de la Computación Móvil, Universidad Tecnológica de Panamá, Panamá, SENACYT
²Gises, Universidad Tecnológica de Panamá, Panamá

Corresponding author: Professor Miguel Vargas-Lombardo, PhD, MSc, Eng, Universidad Tecnológica de Panamá, E-mail: miguel.vargas@utp.ac.pa. ORCID ID: https://www.orcid.org/0000-0002-2074-2939.


ABSTRACT

Background: This study brings innovation oriented to the development of e-health services to improve the performance of healthcare and hospital care in free-living activities.

Objective: This article seeks to propose an innovative mobile software that enables the contextualization of clinical data, while integrating the fundamental functionalities and usability criteria of a mobile health (mhealth) system.

Methods: We examine the utility of a context-sensitive mobile electrocardiogram (ECG) collection system for the detection of cardiovascular diseases for patients in free-living conditions.

Results: We propose an mhealth system that reinforces conventional healthcare systems in which electronic health records are limited by access and processing of data, limiting clinical–medical decision-making. This study highlights the importance of mobile applications for self-care and their usefulness for both patients and healthcare providers. The proposal offers an avenue for the study of contextualized ECG collection methods that can be used to create context-specific actions that reduce false alarms in computer-aided diagnosis of ambulatory ECG.

Conclusion: Mobile applications for health care and monitoring improve the quality of life of people with cardiovascular diseases.

Keywords: cardiovascular diseases, context-sensitive ECG, electrocardiogram (ECG), mhealth, mobile health.

1. BACKGROUND

Globally, cardiovascular diseases (CVDs) caused 17.9 million deaths (31% of all deaths) in 2016 (1). Atrial fibrillation (AF) and atrial flutter are the leading causes of heart failure, hospitalization, thromboembolic events, and mortality (2, 3). Thirty percent of AF patients are unaware that they have AF (4). Early detection and treatment of CVDs are essential for timely health care and prevention of life-threatening situations (5). In Panama, according to statistics from the Ministry of Health (Minsa), 51% of deaths are associated with noncommunicable diseases (NCDs), of which 26% corresponds to CVDs (6). Patients with this disease should actively participate in its treatment, and new technological tools are effectively useful in this task. For this reason, innovation in numerous fields of technology has led to the creation and development of computer systems for health care, which use tablets, cell phones, the Internet, wireless networks, portable devices, and other devices to monitor medication consumption, blood pressure, and blood glucose, among other referrals (7–9). Mobile applications can assist in health-related tasks, including clinical data collection. These applications allow professionals to monitor patients’ health, verify and exchange information, and identify health problems (10). This work is organized as follows: the presentation of a first prototype of a system called university clinic for the Technological University of Panama (2020), whose objective is to build a registry (electronic record) to record the ailments that afflict students, professors, and administrative staff; the first prototype uses the international classification of diseases (ICD-10) (11) for the categorization of diseases of participants; however, the new prototype system has a more updated version oriented toward mhealth technologies based on ICD-11 (12).
the new version, the architectural concept of microservices for mobile technologies is used.

In view of the great difficulties in cardiovascular diseases (13), an mhealth model is presented to serve the university population using mobile technology.

2. OBJECTIVE
The main objective of this research is to develop a contextualization of clinical data of patients requiring accurate monitoring and diagnosis of CVDs. As a secondary contribution, an overview of the microservice architecture proposed for the mhealth system is established.

3. MATERIAL AND METHODS
The controller view model was used for the development of the first version of the system as well as the user-centered design (14, 15). In addition, wireless mobile devices such as blood pressure monitor and glucometer and scales were incorporated into this system (mhealth prototype) to collect data digitally and autonomously. The approach included the following steps in the methodology:

3.1. Search strategy
Initially, Android mobile applications were identified in the online store, using phrases such as "health monitoring," "heart rate," "tele-health monitoring," and "cardiovascular." In this way, we were able to examine their usability and context of use around the user (patient).

3.2. Construction of usability criteria
In accordance with Nielsen decalogue (16), the good practice guide for the development of mobile web applications (17), and the study of comparable works (18-23), various usability criteria were constructed for the development of tele-monitoring-based systems, which are described in detail in Table 1.

3.3. Analysis of binding parameters for software usability
Based on the classification criteria described above, we examined the features and functions offered by the most popular mhealth system telemonitoring management applications in the Google Play store, such as TeleSaludApp, Health Monitor, Tele Salud, CardioCal, Cardiograde–Cardiograph, Ritmo Cardiaco–Monitor Pulso, Cardi Mate: Frecuencia cardiaca, Monitor de ratio cardíaco, and Monitor de pulse cardiac. Table 2 highlights the usability of each application according to the previously established criteria and shows the results of the research according to the established objectives.

4. RESULTS
Following the method indicated by Cooper (24), the entire system design process was carried out by identifying the context of use of the physician, nurse, and patient. Thus, for the identification of contexts of use in the clinical environment, the patient-clinician-designer approach was applied (25), where activities such as initial meeting; design meeting; observation of the clinical laboratory; post-observation design meeting of the laboratory; start of the app design; selection of the mobile detection framework; selection of the ECG reading artifacts; start of the app development; and the intervention of patient, nurse, and associated physician for prototype testing were carried out. These activities allowed the identification of the context of use of the system from a clinical and patient perspective. Subsequently, mhealth telemonitoring applications were examined. Table 2 summarizes the main advantages of each application according to the level of usability compliance, determined by the established criteria. Thus, it was possible to identify points of improvement for the development of the mobile application.

4.1. Proposed system
This research helped us identify the characteristics and usability of each application, so that we could build a new prototype application for telemonitoring patients with CVD in compliance with the 11 established criteria and the good practice guide for the development of mobile web applications (17). Figure 1 shows the overview of the proposed system.

The system was developed to optimize the capture of clinical data of university patients, moving from a manual paper-based process to an interactive electronic health record process. From the context of physician, nurse, and patient use, a system was designed focusing on ECG data collection through a portable ECG device, data visualization in the application, and patient-reported symptoms. The system allows for ambulatory, contextual, and patient-reported ECG collection. Since no cardiologist would supervise the patient’s use, the proposed system allows for backup and interoperability between the system and its component technology compo-

<table>
<thead>
<tr>
<th>Usability Criteria</th>
<th>Description</th>
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<tr>
<td>System visibility</td>
<td>It is the property of keeping the user permanently informed about what happens when interacting with the system.</td>
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<tr>
<td>Congruence between the real world and the system</td>
<td>The system must interact with the user in the user’s language, considering both the text and the order of execution of the actions.</td>
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<tr>
<td>Flexibility and efficiency of use</td>
<td>An interface must provide the necessary resources to perform tasks according to the type of user and the layout.</td>
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<tr>
<td>Design and aesthetics</td>
<td>Each element of the interface must focus its attention on text or images (visual design), which are important for performing operations or tasks.</td>
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<tr>
<td>Help documentation</td>
<td>It is suggested that this information should be easy to find and task oriented for the user.</td>
</tr>
<tr>
<td>Advanced idea mechanics</td>
<td>The user should know the purpose of each interface offered by the system.</td>
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<tr>
<td>Applicability</td>
<td>It refers to the user’s perception of the system.</td>
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<tr>
<td>Satisfaction</td>
<td>It is the set of features that make the system easy to use. The user can recommend it among other similar systems.</td>
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<tr>
<td>Interactivity</td>
<td>It is necessary that the user interfaces are interactive to facilitate their use and comprehension.</td>
</tr>
<tr>
<td>Feedback</td>
<td>It is supported by sensible and summarized information, provides quick answers, and shows content of important concepts of the system.</td>
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<tr>
<td>Activities</td>
<td>Activities should be clear and concise for each section or domain; in addition, they should be in accordance with the service and tasks in execution.</td>
</tr>
<tr>
<td>Error messages</td>
<td>Messages should be written in a language that the user can understand, without technicality, and should suggest a solution or way out.</td>
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</table>

Table 1. Selection of usability criteria for telemonitoring system based on specialized literature.
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For acute symptom diagnosis, for real-time monitoring, allowing the patient to see the status and medical clinical history in which he or she is; see Figure 1B. In addition, there is a volatile and persistent storage in the system, that is, all the data that moves through the system eventually ends up in a set of clusters, which is integrated with different databases; each one has a specific function such as persistent storage of main application data, time series data such as device telemetry, version history data of application logic, and input or volatile data; see Figure 1A.

Medical history
The patient’s mobile application includes data such as age, gender, weight, height, blood sugar, blood pressure, among other clinical data.

Data integration
Data integration combines data from different sources (clinical data collection devices) to create meaningful and useful contextual information. The integration procedures are capture, alignment, linkage, and fusion. Data integration standardizes data across sources and stores it in a repository or health cloud for further study.

4.2. Proposed microservice architecture
Figure 2 shows the architectural concept of the proposed system. Current technologies are decomposed into different components using containerized microservices and RESTful APIs (such as JSON). Kubernetes (25) was selected to handle heterogeneous infrastructures, including on-premises hardware and public cloud service providers, which enable container load balancing and elastic scalability.

The architecture includes client software for end users to interact with processing frameworks. IoT clients collect data produced by different IoT sensors and send the collected data to the edge/cloud service (Figure 1A). The health app is in charge of receiving the results processed by the services from the architecture. This client can also react based on the information received (i.e., to gen-

Table 2. Selection of usability criteria for the remote monitoring system based on specialized literature. (x): indicates whether the app meets any usability criteria.

<table>
<thead>
<tr>
<th>Apps</th>
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<tr>
<td>Telesalud App</td>
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<td>Health Monitor</td>
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<td>Cardiogram – Cardiograph</td>
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<td>Ritmo Cardiaco – Monitor Pulso</td>
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<td>Cardi Mate: Frecuencia cardiaca</td>
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<td>Monitor de ritmo cardiaco</td>
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<td>Monitor de pulso cardiaco</td>
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Figure 1A, and B. Overview of the contextualized clinical data monitoring system using biometric devices.

Figure 2. Architectural concept based on microservices.
erate notifications to doctors or nurses) (Figure 1B). In other words, the architectural concept of the system is based on the management of the logical level of microservices, each with privileges in the cloud, to allow access to different functionalities, such as viewing the patient’s medical history; retrieving, modifying, and uploading medical data; managing roles and users; allowing the use of a pre-diagnosis system to recommend guidelines to be followed by the inference system (decision-making) among other microservices (26).

5. DISCUSSION

This research demonstrates the importance of developing telemonitoring-based mhealth systems for context-aware ambulatory ECG collection in the process of CVD screening in free-living situations. An mhealth system must meet user experience and usability requirements to keep patients engaged and informed. This research proposes to be usable and clinically applicable in both controlled (hospital) and free-living (everyday life) environments. In addition, we explored patient views of the system, opportunities for improvement, and contextual information in disease analysis, allowing us to explore the contextual variables of the ECG, as these can personalize the detection methods of a disease, such as cardiac arrhythmia, which is our focus for future research. Hansson et al. (27) confirms this information since user contexts can provoke arrhythmias or frequent symptoms at the onset of arrhythmias. Therefore, contextualization of clinical data around the patient can be used to construct context-specific actions to reduce false alarms in computer-assisted diagnosis of ambulatory ECG.

In Panama, the use of mhealth tools is still uncommon; however, this system proposal is fundamental, since it allows accessibility and low technicality to be used by patients and older adults.

5.1. Future work

Improvements to the mhealth implementation will continue to be made through case studies where we will experiment with an important set of software and usability tests of the system. We will also analyze the feasibility of microservice models and techniques to achieve measurable optimization of responses to various periods of arrhythmia detection by examining the usage behavior of participants as they interact and contextualize their own information within the mobile system over an extended period (i.e., 2–8 months), as the battery discharge rate of data collection devices affects user experience and adherence in any longitudinal detection based on handheld devices. It is important to acknowledge the support of the clinical team of cardiologist physicians who will be validating this proposal.

6. CONCLUSION

An innovative software model for mhealth is proposed, which will be based on the design and contextualized deployment in parameters of software usability indicators in patient-centered context-sensitive longitudinal ambulatory ECG for CVD detection. Another aspect to highlight is the identification of relevant contextual patient information that favors improved disease or symptom detection when combined with ECG data. In addition, a second contribution is the architectural model based on computational cloud and microservice paradigm as well as the description of technical implementation for an mhealth application based on technological add-ons independent of the contextual ECG collection device. As such, this article presents promising results in terms of system usability for CVD diagnosis and monitoring in free-living conditions.

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