Handling ECG Vital Signs in Personalized Ubiquitous Telemedicine Services

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Abstract. Nowadays, telemedicine services are based on real time acquisition and processing of several types of in vitro patient data, especially vital signs. In this context, the storage, transmission, and management of digital ECG signals are major topics of debate and research nowadays as ECG is one of the most commonly performed examinations all over the world. Hence, many efforts have been already spent in constructing low power and small size ECG biosensors as well as in developing the adequate protocols for organizing and assessing the collected data. Despite SCP-ECG is the common accepted protocol, an excessive amount of ECG formats has been proposed and implemented by a plethora of researchers. This paper presents the SCP-ECG protocol and surveys the current state of medical frameworks and systems for collecting and organizing ECG data and other biosignals' data that are commonly used for the provision of personalized and ubiquitous telemedicine services.

Keywords: SCP-ECG protocol · Telemedicine services

1 Introduction

The electrocardiogram (ECG) helps the health-care providers to provide healthcare services to patients with heart problems. The analysis of the patients' electrocardiograms can exclude the problems of heart rotation, rhythmic and conduction problems, and some symptoms of specific diseases. More precisely, ECG signal is the process of recording the electrical activity of the heart over a time period using surface electrodes placed on the skin. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscle's electrophysiologic pattern of depolarizing and repolarizing during each heartbeat. The final signal passes through various types of human tissues, that add a certain amount of electrical noises. Many external sources also account to this noise.

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ECG is the most commonly performed examination all over the world. So, its transmission, the storage and the management are major topics of discussion and research nowadays. An excessive amount of ECG formats has been proposed and implemented by a plethora of researchers. For transmission and remote management of ECG signals, the most well-known and commonly used is the Standard Communication Protocol for Computer assisted Electrocardiography (SCP-ECG) established by the European Standard Committee (CEN) for ECG recordings.

SCP-ECG is a standard that defines the data structure and format for a patient's ECG signal and demographic data, as well as rules for the above data interchange between digital ECGs and remote computer systems. More specifically, it introduces specific ECG traces, annotations, and metadata that define the interchange format and the messaging procedure. It stores also compressed data by known algorithms. It is recommended as an alternate to ECG databases.

Despite the advanced functionality of SCP-ECG, there is a need for adding extra patient's medical information except the required by the physicians during various telemedicine projects earlier [1]. The e-SCP-ECG^{+} [2] is a remarkable extension of SCP-ECG that introduces new tags for extra demographic related data and data reference to the medical equipment [1]. It also defines additional sections for handling extra vital signals: noninvasive blood pressure (NiBP), body temperature (Temp), Carbon dioxide (CO2), blood oxygen saturation (SPO2), and pulse rate, and allergies, which are required for an integrated remote health monitoring.

Structuring of Personalized Ubiquitous Telemedicine Services (PUTS) is a key factor for providing high quality remote health monitoring. This paper, firstly surveys the structural, operational and performance attributes of the most expanded ECG and daughter protocols that could be exploited within the PUTS context. Section 2 examines the fundamentals of SCP-ECG. Section 3 discusses the current proposed frameworks and systems for handling ECG vital signs. Finally, Sect. 4 proposes specific expansions of SCP-ESC guided by PUTS context.

2 The Fundamentals of SCP-ECG Protocol

2.1 SCP-ECG Scope

With the increasing user acceptance and commercialization of digital electrocardiography and ICT technologies, the SCP-ECG came to allow the storage and the exchange of ECGs between medical ECG devices and user systems. Nowadays, it is integrated in the ISO/IEEE 11073 family of standards and the goal is to interoperate with other medical devices and not only ECG specific.

For this reason, SCP-ECG structures a binary encoded format of data and mechanisms for the signal's compression and the final reduction of the file's size. So, the ECGs are transmitted with low transmission ratios and the resulting disk space is used for the storage of the signal. This standard also handles ECG measurements, ECG feature extraction, pattern recognition, ECG interpretation and diagnostic classification.

Regarding SCP-ECG compliant software, there are many freely available programs including viewers, writers, parsers, format and content checkers. There are also methods for the harmonization of this ECG standard with others, such as the DICOM Waveform Supplement 30 [3], HL7 aECG [4] and MFER (Part 2.6 of the protocol).

2.2 SCP-ECG Structure and Data Content

As mentioned before, SCP-ECG integrates a patient's ECG data structure, an elementary demographics format, and also, the rules for interchanging data between digital ECG carts and hosts that, respectively, obtain and store the ECG data. An SCP-ECG formatted file divided in twelve (12) sections -dedicated per information category- includes all this information referred above. Finally, it includes several sections for the handling of manufacturer-specific content that can adequately handle various types of information through continuous health monitoring applications, and there are also some free sections for future use.

Each one of the 12 sections is defined by its own specific encoding rules and preceded by a common header. Regarding their contents, they may be divided in the following six different groups of information:

Group 1 (including entire Section 0): it stores the pointers to the start of the remaining sections in the record. This section is considered as public.

Group 2 (including tags 0–3, 5, 14–26, 31 of Section 1): these fields include the identification of the patient and the physicians, institutions and all the devices used for the acquisition, analysis and diagnosis of the ECG. This information is considered as highly confidential since it can identify the patient in a file full of health data.

Group 3 (including tags 4, 6–13, 27–30, 32–35, 255 of Section 1): these fields incorporate general information about the patient (e.g. age, weigh), his health condition (e.g. medical history, drugs) and data for the correct interpretation of the ECG (type of filtering applied). In terms of privacy, these data itself do not identify the patient.

Group 4 (including Sections 2–6): these sections identify the present leads in the record (Section 3) and store the ECG signal data (Section 6), which may be stored as uncompressed raw data or alternatively compressed using different algorithms. The compression ratio which can be accomplished ranges from less than 2–4:1, when only using Huffman tables (Section 2), or up to 6–20:1 when combining second-order differences (using Sections 4 and 5) with Huffman encoding and downsampling, at the cost of lower signal quality.

Group 5 (including Sections 7–11): these sections can be optionally added to incorporate: (a) global measurements (Section 7) and measurements from each lead independently (Section 10), to help the physician's work, and (b) the diagnostic interpretation of the ECG record (Section 8), which must be consistent with the manufacturer interpretive statements (Section 9) and the universal ECG interpretive statement codes and coding rules (Section 11). These data help to interpret the patient's ECG, so if he is identified, this information must be considered as highly confidential.

Group 6 (including Sections numbered 12 to 127 and those above 1023): these sections are reserved for future use.

3 Current Proposed Frameworks and Systems for Handling ECG Vital Signs

This section describes the main existing frameworks and systems for collection, management, processing, and transmission of ECG data.

3.1 ECG Data Collection by Biosensors

Biosensors are the devices that capture the biological signal and convert it into a detectable electrical signal. There are several classifications of biosensors employed in this scientific field. For instance, based on the application site, biosensors are distinguished in wearable, mobile, implanted, ingestible and ambient.

In some studies, ambient sensor networks for environmental monitoring are employed in conjunction with WBANs, to augment medical data with patient's context data (e.g. temperature, humidity, luminosity and movement). Along this context, for the remote monitoring of patients, the typical mobile system is a three-tier network architecture [5], especially in situations of elderly or chronic patients in their residence. The lower tier incorporates two systems: an integration of suitable medical sensors equipped with a Bluetooth transceiver; and the ambient wireless sensors deployed in the patient's surroundings. In the middle tier, an ad hoc network of powerful mobile computing devices (e.g., laptops, PDAs) collects the demographics, medical and ambient sensory data and forwards them to the higher tier. The middle-tier devices must be equipped with several network interfaces in order to communicate with the lower tier and WLAN or cellular capabilities for the higher layer. Finally, the higher tier is structured on the Internet and incorporates all the application databases and servers accessed by the healthcare providers. The proposed framework provides a flexible and secure solution that can be applied to several scenarios, including home, hospital and nursing home environments for the monitoring of multiple patients.

Moreover, for the monitoring and location tracking of patients within hospital environments a group of researchers proposed a system architecture based on two independent subsystems [6, 18]. The healthcare monitoring subsystem consists of smart shirts with integrated medical sensors. The location subsystem has two components: IEEE 802.15.4 end devices, on the patients, that gather signal strength information from the received beacons, and a deployment of wireless IEEE 802.15.4 nodes that are installed in known locations within the hospital infrastructure and broadcast periodic beacon frames. Both subsystems forward their acquired data to a gateway through an IEEE 802.15.4-based ad hoc distribution network. The gateway has wired Internet connectivity and forwards the data to the management server and the monitoring mHealth application, that the healthcare providers have easily access. The proposed system achieves real-time data reconstruction, high reliability, and sufficient battery lifetime of the sensors used.

It is well-known that low power wireless sensors, personal wireless hub (PWH) and receivers can reduce the workload of the paramedic staff in a hospital. In this context, Naeem et al. [7] used several PWHs to transmit sensory data to the main central controller. A well designed multiple PWH assignment and power control scheme can decrease the electromagnetic and in-band interference induced to the other medical devices in the hospital. They proposed a framework and an algorithm with low complexity for interference aware joint power control and multiple PWH assignment (IAJPCPA) in a hospital building with cognitive radio capability. They presented an efficient PWH assignment and power control scheme for IAJPCPA.

Later, the same researchers [8] extended their work presenting an advanced study about Wireless Resource Allocation in Next Generation Healthcare Facilities. Healthcare facilities with intelligent wireless devices can decrease the workload of the paramedic staff. These devices incorporate low-power wireless sensors, personal wireless hub (PWH), and receivers. The PWH acts as a relay in the hospital network. To help the wireless sensor devices, they used multiple PWHs to forward sensory data to the main central controller. It also enhances reliability to the coverage of the wireless network. In the proposed framework (IAJPCPA), any wireless sensor device can send and receive data from multiple PWHs. The main objective of IAJPCPA is to maximize the total transmission data rate by assigning PWHs to the wireless sensor devices under the constraint of acceptable interference to the licensed wireless devices.

3.2 Transmission of ECG

A large-scale study was carried out about the characteristics of transmission media in the healthcare system, and design various telemedicine systems by using advanced wireless communication technique, while Telemedicine performed by employing a highspeed and robust advanced wireless communication system, such as the healthcare system can provide ubiquitous medical services at any time.

Researchers are endeavoring along this promising path. Lin and Yi-Li [9], proposed a direct-sequence ultra-wideband (DS UWB) transmission system for wireless telemedicine system. An essential feature of this system is that it provides larger power and schemes offering significant error protection for the transmission of medical information that requires higher quality of service. To achieve maximum resource utilization, or minimum total transmission power, they also incorporated an M-ary Binary Offset Keying (MBOK) strategy into the system. Thus, in their proposed medical system, high power, a long length MBOK code, and scheme providing significant error protection schemes are employed for the transmission of medical messages that require a stringent Bit-Error Rate (BER). In contrast, low power, short length MBOK codes, and less capable error protection schemes are provided for messages that can tolerate a high BER. The resulting model is being verified by a simulation carrying out the proper functioning of the proposed system in a practical wireless telemedicine scenario.

Later, Lin and Yi-Li [10], expanded their research work proposing a power assignment mechanism for direct-sequence ultra-wideband (DS UWB) wireless telemedicine system with unequal error protection. Their analysis was followed up by a simulation to validate the proper functionality of the proposed DS UWB wireless healthcare system.

In other work, the multiple transmitter relay pairs desire forwards their gathered information to a main data center. This relay-aided hospital wireless systems in cognitive radio environment was investigated in [18]. For that system, the proposed transmission framework follows IEEE 802.22 WRAN and adopts the listen before talk and geolocation/database methods to achieve the protection of the primary users. Regarding the proposed transmission strategy, in each subsystem, the wireless sensor device (WSD) with the highest signal to noise ratio (SNR) is selected to transmit signals at each time and then, a two-hop half duplex decode and forward (DF) relaying transmission is launched among the selected WSD, the corresponding personal wireless hub (PWH) and the data center. As a result, an optimization problem is formulated to maximize the system sum rate via power allocation. They then solved it by using convex optimization theory and KKT condition method and derive a closed form solution of the optimal power allocation. By finishing their work, the validity of their proposed scheme is proved by their Simulation results, showing also the effects of the total power, the interference thresholds and the scale of the network on the system performance, which offer some insights for practical hospital wireless system design.

3.3 Management and Processing of ECG

A plethora of researchers work on automatic pattern recognizers using Artificial Neural Networks (ANN) and compound neural network (CNN). Nowadays, the development of independent processor-based structures with sufficient processing capabilities is an emerging technology in order to make early and accurate diagnosis so as to provide early treatments [11–13]. Today, we tend to rely a great deal on the application of pattern recognition methods to help us achieve such a goal. In this line, several studies of automatic recognition of ECG data have been proposed.

Meghriche et al. [14] developed two approaches. In the first one the Compound Neural Network (CNN) is structured in three different multilayer neural networks of the feed forward type, and the second one based on only a multi-layer perceptron (MLP). The result is that in both approaches there is the capability to classify ECGs as carrying atrioventricular blocks (AVB) or not. Finally, they concluded confirming that neural networks can be reliably used to improve automated ECG interpretation process for AVB and also that this kind of networks can be used as an accurate decision-making support by even an experienced healthcare provider.

De facto, digital medical examinations are one of the pillars for the expansion of e-health, a new medical paradigm which enables the implementation of new ICT-based services and the decrease of the patients' and healthcare systems' costs. Personal patient data and health status, ECG measures or the diagnosis are mainly stored as metadata in a digital ECG file. As a result, there are several governmental regulations that protect these examinations both at the storage point and during transmission. Reliability and privacy are the two general requisites must be guaranteed.

In this line, Rubio et al. [15] proposed a SCP-ECG security extension. Their work offers SCP-ECG files to be stored safely and proper access to be granted (or denied) to users. The access privileges are scaled by means of role-based profiles supported by cryptographic elements (ciphering, digital certificates and digital signatures). These elements are considered as metadata into a new section. The application's capacity to authenticate users and to protect the integrity of files and the privacy of sensitive data, with a low impact on file size and access time, has been extensively tested. The main advantage of this solution is its combability with any version of the SCP-ECG, so as can be easily integrated into e-health platforms.

3.4 Machine to Machine Systems

Kartsakli et al. [16], presented a comprehensive survey on Machine-to-Machine (M2M) systems. In the new era marked by the increasing number of wireless electronic devices, (M2M) communications are an emerging technology in order to achieve an interconnection between the devices without the human interaction. The use of mHealth applications based on M2M technology provides considerable benefits for both patients and healthcare providers. Hence, at first, they presented an advanced methodological study of Wireless Body Area Networks (WBANs), which establish the enabling technology at the patient's side, and then discuss end-to-end approaches that comprise the design and implementation of applied mHealth applications.

Regarding the mHealth, the M2M approach supports the use of suitable sensor devices on the patients. The medical sensors form a Wireless Body Area Network (WBAN), and mostly they are organized through short-range wireless networks. In the next step, an M2M-enabled gateway node gathers all the sensory data collected from the WBAN and forwards them to a remote online server, where processing and integration with medical-related software applications take place. At that time, they are used long-range communication access technologies for Wireless Local/Metropolitan Area Networks (WLANs/WMANs). The collection of significant amount of data and their timely delivery to the healthcare providers in an unobtrusive way for the patient and autonomously- without needing the human interaction, can significantly facilitate the management of chronic diseases and speed up the early and accurate diagnosis. So, in this context this technology paves the way for new possibilities for mHealth applications, by enabling the telemonitoring of vital signals [17], the early detection of critical conditions and the telecontrol of certain healthcare treatments [18].

There is no doubt that the area of M2M communications for mHealth enjoys a rapidly growing. Despite that, there are still many challenges in the variety of aspects of the mHealth systems. Although, there is the need to standardize the activities and methods, that will enable the market exploitation of the scientific contributions in this field of healthcare services by paving the road for the development of interoperable M2M mHealth solutions and approaches.

Another noteworthy trend is that people all over the world are getting older and this fact has created the need for designing new, ubiquitous and cost-effective healthcare systems. In this respect, distributed and networked embedded systems seem the most attractive technology to achieve continuous telemonitoring of aged people. Along these lines, Tennina et al. [19] proposed recent advancements by introducing WSN4QoL. The project involves the implementation and design of wireless sensor networks (WSNs) specifically structured to meet the existing healthcare application requirements. In particular, the system architecture is presented to deal with the challenges imposed by the specific application scenario. This incorporates a network coding (NC) algorithm and a distributed localization approach that have been implemented on WSN testbeds to achieve efficiency in the communications and to enable indoor people tracking.

4 Discussion

Nowadays, we are already on the transition from the traditional desktop-based computing technologies towards ubiquitous computing environments that will enfold us in almost all our daily situations and activities. Simultaneously, there is an amplified tendency of creating a patient-centric service delivery. As a result, the services in the ubiquitous environments should be adapted to the current context, the needs and the preferences of users. As a result, mobile and pervasive health systems encompass complex mechanisms to collect and process an increasing range of data, instead of simply acquiring, analyzing and interpreting purely medical data.

For instance, the majority of contemporary health systems that rely on ECG measurements to deliver healthcare services are increasingly taking into account accelerometer data to distinguish abnormal ECG measurements due to pathological reasons from abnormal ECG measurements caused by certain activities (e.g. running). In addition, location information is deemed a prerequisite to deliver appropriate care in case of a critical cardiac episode. Apart from context data, preferences of patients (e.g. who to be informed when care provision is required), play an important role in personalizing service functionality and achieving higher degrees of user acceptance and market diffusion.

The above and many other cases suggest that protocols, frameworks, and systems for ECG data transmission and management should also consider data referring to non-medical aspects of a patient, such as location, activity and temporal information, or, in other words, the context of a measured ECG and a reasoned health status. Nevertheless, while infrastructural capabilities of pervasive health systems, in terms of sensing devices, middleware architectures, as well as service logic approaches (i.e. data analysis technologies), have addressed this need, it is also essential traditional ECG oriented protocols to incorporate contextual information by integrating additional sections in the protocols' structure.

5 Conclusions

After decades of continuous work in information systems dedicated to the healthcare domain, there is a growing demand not only for hospital-based care but also for personalized and ubiquitous healthcare delivery. For example, an especially critical healthcare domain is cardiology; almost two third of cardiac deaths occur out of hospital, and patients do not survive long enough to benefit from in-hospital treatments. For this reason, it is needed to adopt new healthcare models that enable continuous patient monitoring without spatiotemporal restrictions and orchestrate timely care provision moving the point of care beyond traditional healthcare settings. The ECG is only immediate diagnostic test to prevent a cardiac event. The early detection of cardiac events requires advanced decision-making techniques guided by reliable alarm messages and involving care provider only if necessary. Above all, there is the need the patient to control its own health status by being able to perform related tests at the early stage of the onset of the symptoms without involving skilled personnel and healthcare providers. The solution should be a combination of medical protocols, frameworks and systems for collecting, transmitting, managing, and organizing ECG data and other biosignals' data that are commonly used for the provision of personalized and ubiquitous telemedicine services.

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