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Viability study of a personalized and adaptive knowledge-generation telehealthcare system for nephrology (NEFROTEL)

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ABSTRACT

Objectives: Several important problems in the majority of countries are challenging the centralized and overburdened current model of healthcare. Telehealthcare is presented as a new paradigm that offers high expectations to solve this picture. In this paper we present the major outcomes of the viability study of a novel personalized telehealthcare system for nephrology (NEFROTEL).
Methods: The study evaluates the accuracy and quality of the knowledge generated by two key processing layers, namely, sensor layer and patient physiological image (PPI) layer, in an independent way, thanks to its modular design. The first one was defined by a personalized falling detection monitor, on account of the consequences of falls in chronic renal patients. The second one was analyzed by means of a PPI's prototype based on a urea compartmental pharmacokinetic model. The experimental study of the falling detector monitor has been more extensive than the other because the latter has already been addressed in other works.
Results: The outcomes show, firstly, the capability of the PPIs to provide integrated and correlated physiological knowledge adapted to each patient, and secondly, demonstrate the reliability of the impact detection function of the adaptive human movement monitor compliant with the NEFROTEL paradigm.
Conclusions: The study confirms that NEFROTEL is able to provide knowledge concerning a patient in a manner that cannot be accomplished by the ordinary healthcare model at the present time.

1. Introduction

The growth of chronic pathologies such as diabetes mellitus, end stage renal disease (ESRD), hypertension, and cardiovascular diseases, the aging of population and the associated expansion of degenerative disorders such Alzheimer or Parkinson diseases, the change of social models and structure of family, and the new threats coming from the accelerated worldwide spreading of infectious diseases due to the impact of migration and population movements in a globalized world, are challenging the centralized and overburdened current model of healthcare [1–5].

Telehealthcare is presented as a new paradigm that offers high expectations to provide effective solutions to this picture. Telehealthcare systems pursue the improvement and decen-

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tralization of healthcare services, allowing the geographical separation between patient and physician. These goals have pushed the research in novel, non-invasive, and ubiquitous sensors, multimedia services, and communications networks, from a multidisciplinary perspective [6,7].

Telemedical information systems (TIS's) are showing their important role for an adequate implementation of telemedicine applications, extending the telemedicine services for providing access to the health information system (HIS) and the electronic patient record (EPR) [8]. This is pushing the emergency of a knowledge-based telehealthcare. However, in spite of the important role that medical knowledge discovery has acquired, as shows its inclusion into 1 of the 20 building blocks identified by the Euromed project [9], as well as its consideration into several of the major HIS research lines up to now [10], insufficient efforts have been devoted to generate useful medical knowledge in a real-time fashion from signals and data. Advances in knowledge discovery have been mainly oriented to the detection of data patterns that could assist in medical diagnosis, but unfortunately, this line has been aimed at the off-line processing of data. As an example, we could cite the knowledge-based approach developed by Bousquet et al. for pharmacovigilance [11].

A recent review regarding the potential advantages and risks associated with health information technologies (HIT's) has shown the huge investments performed in this area despite the hardly advances in their adoption and in the improvement of patient outcomes [12]. It concludes that HIT will be widespread adopted because of the inexorable growth of the health expenditure and the need to provide solutions to the healthcare challenges, but the question "how best to promote the adoption of HIT to transform healthcare" awaits a response [12].

In agreement with [9,10], we think that a plausible response is to promote an evolution in the central paradigm of HIT towards a personalized and adaptive knowledge-based telehealthcare. Accordingly, we have developed a novel methodological approach for generating real-time personalized and adaptive biomedical knowledge in telehealthcare [13,14]. The biomedical knowledge is provided by means of a computational image of the patient state focused on the desired biomedical domain (e.g. renal). It is built by a smart sensor layer and a *patient physiological image* (PPI) layer, being computed as distributed subsystems. Each layer generates knowledge from the input data, adapting to each user and his/her context. This way the information generated in the smart sensor layer is used by the PPI layer, which provides an advanced supervision of the patient. Our previous studies suggest that this methodology is able to build an integrated biomedical image of the patient state and could help to predict events and system malfunctions [13,14]. It also has the ability to integrate biomedical information belonging to different living scales, in agreement with current trends in system biology [15,16] and even in HIS [10].

This article presents the major outcomes of the viability study of a personalized and adaptive telehealthcare system for nephrology (NEFROTEL), based on that methodology. The study evaluates the accuracy and quality of the knowledge generated by both layers in an independent way, taking advantage of its modular design. The first layer was defined by an adaptive and personalized human monitor used for falling detection. This variable was selected on account of the serious consequences that falls produce in patients with chronic renal disease, due to their muscular loss, lack of D vitamin, and incidence of arthropathy by β_2-microglobulin [1].

The second layer was built by means of a PPI's prototype based on a compartmental pharmacokinetic model. This is able to generate useful medical knowledge related to ESRD patients submitted to periodic hemodialysis (HD) [17,18]. The description and analysis of the smart falling detector is more extensive than the PPI's prototype, because some technical details and study-cases regarding the PPI have already been presented [13,14].

2. Description of NEFROTEL

Fig. 1 shows a simplified block diagram of the computational architecture of a NEFROTEL prototype (left), together with the processing stages that the biosignals follow after their acquisition (right). The diagram emphasises the two processing layers involved in the real-time generation of personalized and adaptive biomedical knowledge that characterizes the methodological approach of NEFROTEL.

This telehealthcare system is composed by three scenarios. The *Remote Access Units* (RAU's) connect the assisted user to the provider center by means of a simple phone link to the Public Switched Telephone Network (PSTN) [14]. This is the minimum technical communication requirement of the RAU, which guarantees a nearly universal and inexpensive access to the system [19]. The *Professional Access Interfaces* provide to physicians and professional users different types of accesses to the system. The third scenario refers to the *Telehealthcare Provider Center*. This subsystem was designed as a multi-tier architecture, in order to avoid the bottleneck of the database management system (DBMS). Signals are sampled and processed by the smart sensors and sent through RAUs to the Provider Center, where they are processed taking into account their priority. A Supervisory Control and Data Acquisition (SCADA)-based module performs a subsequent analysis and conditioning of this information, which is mainly stored in an object-relational database (PostgreSQL) and prepared to be used by the PPI computational modules. The following subsections deepen the description of the key methodological features of NEFROTEL and present the implementations justified in Section 1, with the aim of testing the viability of this system.

2.1. *Smart sensor layer*

The sensor layer of NEFROTEL is complex, as it involves different sensors, sample periods, and acquisition procedures, from real-time to manual inputs (e.g. pre- and post-dialysis blood samples). We present here a novel wearable human movement monitor (patented), which was developed according to the methodological approach of NEFROTEL, and is used as a smart sensor. It measures body accelerations to compute postural and kinematic variables of the assisted user, as well as the energy expenditure caused by physical activity. An interesting added value of this sensor is the detection