15th Triennial World Congress, Barcelona, Spain

RENAL DISEASE HEALTHCARE CENTER BASED ON A COMPUTER PHYSIOLOGICAL IMAGE OF THE PATIENT

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Abstract: The Patient Physiological Image (PPI) is a novel concept that manages the knowledge of Virtual Center for Renal Support (VCRS), currently being developed by the Biomedical Engineering Group of the University of Seville (GIB). PPI is a "virtual" replica of a patient, built by means of a mathematical model. From a technical point of view, PPI is a component-oriented software module based on cutting-edge of Modeling and Simulation Technology. In this paper we first state the features that the PPI component must fulfil to support the VCRS functionality. From those, the VCRS-PPI software architecture is described. *Copyright © 2002 IFAC*

Keywords: Medical Systems, telematics, dynamic modelling, simulation, knowledge-based systems, programming approaches

1. INTRODUCTION

End Stage Renal Disease Population (ESRD) is growing with a raising slope near 7% average per year in developed countries (USRDS, 2000). The public healthcare system costs associated with this population are also increasing, but in a more dynamic way. The increase in quality of life and also in percentage of elderly people into ESRD population, are the main reasons for the evolution of ESRD health program economical costs. This background is not readily solvable by current health programs strategies, because of the low natality and high life expectation, which compel governments to unbalance the public expense. In addition, renal replacement therapies outcomes are still low and although more investigation about uremic syndrome, secondary pathologies related to renal dysfunction and membranes behaviour are needed, the improvement in renal replacement therapy is an achievable goal with current knowledge.

The reduction of journeys to dialysis center by means of home dialysis improves patient quality of life, as several studies have shown, a recent example from Canada is presented in (McPhatter et al., 1999). In addition, the successful improvements in quality of life, which has already been obtained with daily hemodialysis (HD) (Mohr et al., 2001), could be adequately implemented by home HD therapy. However, home dialysis has not had a widespread use because of the lack of physician support that produces.

The remote healthcare paradigm has emerged as a new approach to healthcare services from the present-day explosion of novel ideas and applications on the information technology domain. The remote healthcare concept has just been started to use for patients with renal dysfunction and HOMER-D (EHTO, 1998) in hemodialysis is an important exponent.

Taking as aim the overcoming of several restrictions of these previous architectures for renal patients, the Virtual Center for Renal Support (VCRS) Project has recently been defined (Prado et al., 2001). VCRS is a novel remote healthcare system that provides a knowledge-based assistance to renal patients by means of modeling and simulation technology. The Patient Physiological Image Component (PPI) provides the major knowledge base to VCRS. This work firstly develops the PPI features that are needed and finally proposes a technological approach to fulfil with them.

2. PPI FEATURES

The Patient Physiological Image (PPI) is the instrument by which the Virtual Center for Renal Support provides an advanced remote assistance for ESRD patients and support for renal therapy trials. These functions are mainly related to the way from which knowledge is discovered and managed by VCRS and therefore by the physician. A best knowledge about renal patient state allows a more personalized and optimal design of renal therapy by physicians. Previous studies have shown that nowadays the monitoring requirements of renal patients are not being achieved (Agodoa et al., 2000). However, if the patient increases the number of visits to the medical center to yield with more frequent blood samples and monitoring, his quality of life may be affected (Prado et al., 2001). Home healthcare systems based on information and communication technologies are a good solution, providing a fast link between patients and physicians to transmit the necessary monitoring data. This is especially important during dialysis session and with that aim HOMER-D Project has treated to fill the supervision gap between patient and physician by means of an ISDN port (EHTO, 1998; Carson et al., 1998).

However, VCRS is not limited to patient telemonitoring, but provides a deeper knowledge about the patient and therapy equipment. To achieve this goal, PPI component manages the following knowledge issues into the VCRS system.

Temporal correlation. The significance of a clinical variable value is strongly dependent on the other clinical variable values at the same time. The temporal correlation is not usually taken into account because there is not enough information from the patient or because the information has been taken at different instants. In this way, the physician must use his experience and knowledge about the patient to interpret a clinical value. VCRS solves this problem placing a PPI component, with the ability to discover knowledge, between monitoring signals and the information given to the physician. This task is done by means of a computer-implemented model.

Dynamics vs. static. Clinical monitoring is oriented to obtain patient health state snapshots. In this way, dynamic physiology knowledge is lost, despite its richness of information (Gu and Asada, 2000a). To recover dynamic from snapshots, the PPI component will use a dynamic systems methodology.

Observability. Many clinical variables are not frequently measured because of the complexity of the procedures, cost and harm that the measurement can produce to the patient. In other cases the necessary data cannot be directly measured and require the knowledge of many other quantities. The PPI component must increase the observability of the patient, allowing the physician access to non-monitored quantities, which are needed to a better understanding of the patient health state.

Predictability. When a patient is receiving clinical treatment far of the medical center, increasing the security is an important task, overtaking possible complications that may occur during the therapy session. The prediction of a severe hypotension during hemodialysis session, for example, would help patient and physician to avoid this event, by taking a corrector action. The VCRS architecture, by way of PPI components, will even allows the trial of corrector actions on patient's PPI, adjusting the operation in an interactive manner, before the immediate application to the patient. For example, a recent work proposes a numerical simulation to hemodialysis-induced hypovolemia (Cavalcanti and Marco, 1999) that could be applied with this scheme.

The other aspects of PPI functionality are related to the specific goals of the VCRS architecture, which are described in the two next subparagraphs, followed by a more precise definition of PPI.

2.1 PPI like assistance support

Health assistance possesses two interacting components: physicians and patients. In telehealthcare systems these components are taken away, keeping contact by means of telematics networks. This is the point of view used in many current works (Skouras, 2000). VCRS design starts from a different approach, building an intermediate component with the ability to increase quantity and quality of information from patient to physician. This component is the Patient Physiological Image (PPI). VCRS health assistance design is founded in two functions: On-line Therapy and Personalized Therapy Design.

VCRS system allows therapy to be applied in "on-line" mode. That is, VCRS will provide a simulation environment by means of which the physician can predict the patient response, adjust the therapy (under restrictions stated by the medical team) and test it on PPI component, starting on the current patient state. Finally, the physician can apply suitable changes to the current patient therapy by means of audio or multimedia communications with him. This process is illustrated in Fig. 1.

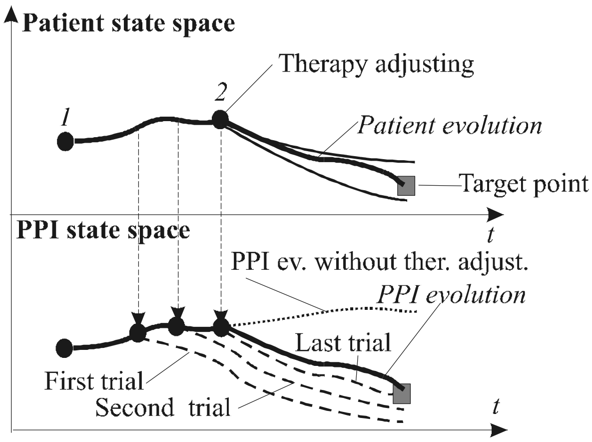

Fig. 1. Patient and PPI state evolution (continuous line) during a therapy session. Therapy trials are done into PPI space, at different instants (circles), by fast simulation. Last trial is accepted and applied to patient (point 2)

This methodology has recently been proposed as a "futuristic" distributed simulation in the military area (Davis and Moeller, 1999). The technical difficulties that arise in distributed simulation are not solved yet, however VCRS health assistance is not based initially on distributed simulation.

The early design of personalized therapies is actually a challenge for healthcare systems. The difficulty arises from two lacks: a better knowledge from patient health state and a framework which assists forward the trial of a new therapy. By means of the VCRS system it is still possible to promote an early therapy design by means of a better knowledge provided by the PPI. The creation of a new PPI component *connected* to a new patient is a key issue in VCRS system. This creation has to use initial data from the patient to identify the better mathematical representation for him/her. Since beginning, the PPI component will be continuously upgrading the pathophysiological representation of the patient and adapting itself to the patient evolution. For that goal, PPI component will run in autonomous mode, feeding itself from patient monitoring data.

2.1 PPI as an open investigation tool

Development of VCRS system supposes a chance to give new technological and scientific solutions into human body simulation environments: a new investigation domain which tries to connect human physiological models developed in a modular fashion to achieve integral aproaches to human body behaviour. This futuristic domain is mainly represented by the Physiome project (Bassingthwaighte et al., 1997), which has agglutinated physiology and biotechnology investigation in different health areas and particularly in the renal system. To achieve this goal, the VCRS technical approach will fulfil with interoperability and reusability topics, allowing the interaction of renal subsystems running on different platforms. VCRS architecture shares concepts with the physiological system simulation environment proposed by Gu and Asada (2000b).

2.3 PPI formal definition

Considering mathematical simulation as a specialized form to access to information, PPI is a software framework capable to represent dynamical behaviour of patient physiology. PPI will be integrated by a set of coupled equations, physical structure instructions, execution control instructions, parameters, state variables snapshot and plug-in interfaces, to allow a complete interaction with PPI. Fig. 2 illustrates this framework. Physical structure instructions define the hierarchical constitution of physiological system represented by the PPI, by means of which, PPI can be readily adapted or partially reused.

PPI framework is a software component from which several software objects will emerge. As software component, PPI will exhibit distribution, modularity and independence of platform or language capabilities, that is, it will place at [1,1,1] position into the *component space*, following the terminology of Stuart Thomason in the work of Brereton and Budgen (2000).

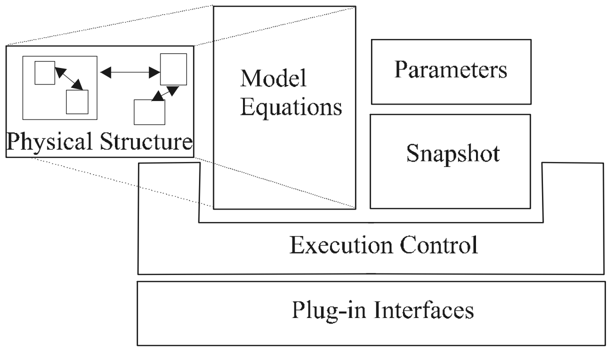

Fig. 2. PPI component framework**.**

3. PPI TECHNOLOGY

PPI implementation is done on two levels. The first level provides a full reusable and interoperable implementation of PPI component. This level does not run directly into VCRS, but must be converted towards several PPI objects before to use it. At the first level, the set of equations is implemented with a XML lenguage, such as MathML. XML allows an open and interoperable transfer and storage of hierarchically classified data as the equations that define the mathematical model. In addition, the majority of modeling and simulation modern environments support XML or are working to do it. XML is also used in Physiome Project to transfer biotechnologic and physiologic data. We have discarded the implementation of PPI component at the first level into any generic computer language as Fortran, C++ or Java, for example, because this forces the conversion of model equations to an algorithmic fashion and in this way PPI component will lack reuse capability. We have also discarded the implementation at this level by non-causal simulation languages as standard Modelica because their dependence with particular environments and platforms.

PPI component evolves towards several PPI computer objects in the second implementation level, where it can already be used into VCRS architecture. These objects are a set of physical modules implemented within any object-oriented and non-causal modeling language, taking Modelica as preference. Conversion between XML-based mathematical equations and computational non-causal modeling language is a natural transformation because of the preservation of equations.

Finally, several modules are connected themselves to constitute the target model which is now prepared to represent the patient physiology. The selected modeling environment does this connection.

The VCRS architecture can be presented by the blocks diagram of Fig. 3. As it was established in a previous work (Prado et al., 2001), VCRS is formed by three types of elements: remote access units (RAU) for patient's access, client interfaces for professional access (CIPA) and resources provider of virtual center (RPVC). The interaction among them is done by means of the database management system (DBMS). The communication links were also studied in (Prado et al., 2001).

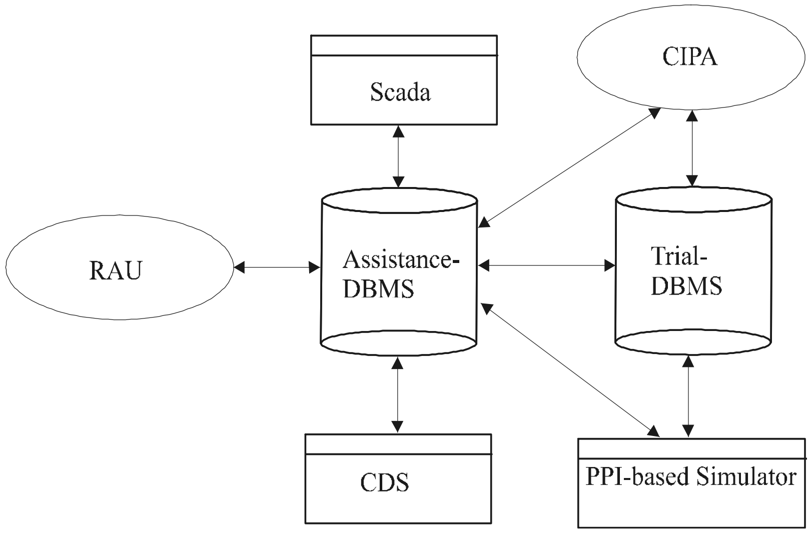

Fig. 3. PPI-based VCRS architecture.

Three major subsystems, PPI-based Simulator, Supervisory Control and Data Acquisition (Scada) and Clinical Decision Support (CDS) constitute VCRS-RPVC computing architecture. Interaction among them is done through DBMS, allowing their implementation within different languages and platforms in an interoperable fashion. These three subsystems cooperate to support VCRS assistance function. Scada does signal preprocessing and filtering to condition clinical measurements monitored in RAU points before the signals can be stored and feed PPI-based Simulator. Scada functions that remain are alarms processing, signals presentation like trend curves or process diagrams and simple signal postprocessing. Simulator-generated signals are also treated in a similar way by Scada to present useful information to physicians. This philosophy has been succesfully used with real-time simulation in other engineering areas, as energy production. Clinical Decision Support (CDS) major function is to build a better knowledge about patient for the physician. This is done through two methods. The first of them is a near-real-time analyzer of patient health state, built from the joining of monitoring data and simulation data. The Second method of CDS is a data-driven system that provides support for diagnosis and prescription. Both procedures have been used in electrical plants performance analysis. The second method has been frequently used in biomedical engineering, for example in Utilities for Optimizing Insulin Adjustment (UTOPIA) project, which has been extended into a telemedicine configuration in (Carson et al., 1998).

Finally, PPI-based simulator is the kernel of this architecture. Data from the PPI model are managed by the DBMS in a secure and key-protected assistance-database, which is presented in Fig. 3. Therapy trials and investigation experiments require the creation of new instances of PPI models that are not related to the on-line evolution of the patient. Data into these latter models are managed into the trial-database.

4. SUMMARY

In this work we have presented a telemedicine architecture for renal assistance that is not limited to patient telemonitoring, but yields a deeper knowledge about the patient and therapy equipment. Starting from ESRD population needs, which were briefly analyzed in a previous work (Prado et al., 2001), we have described the main features to be fulfilled by the PPI component, from which we have done a technological approach to this one within the VCRS system. This technical approach allows the interaction with PPIs in several ways; giving support to the knowledge transfer among different research groups, in line with the Physiome Project.

Because of the cross-platform competence of the modern object-oriented Java language, together with its capabilites as modeling language, distributed computing, thread-oriented programming, and other more specialized features as JIT compilation and 'aglets' mobile agents; we are also researching on the conversion of the source code produced by the selected non-causal modeling environment towards Java.

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