Decision Support for the Remote Management of Chronic Patients

Sara Colantonio[1], Giuseppe De Pietro[2], Massimo Esposito[2], Alberto Machì[2], Massimo Martinelli[1], and Ovidio Salvetti[1]

[1] Institute of Information Science and Tecnologies, ISTI-CNR
Via G. Moruzzi, 1-56124, Pisa, Italy
{sara.colantonio,massimo.martinelli,ovidio.salvetti}@isti.cnr.it
[2] Institute for High Performance Computing and Networking, ICAR-CNR
Via P. Castellino, 111-80131, Napoli, Italy
{giuseppe.depietro,massimo.esposito,alberto.machi}@icar.cnr.it

Abstract. Chronic diseases may cause major limitations in patients' daily living due to acute or deterioration events, which can happen more or less frequently and, often, cannot be totally relieved, causing a worsening of patients' conditions. In the last years, a strong effort is being spent in the development of intelligent ICT applications for patients' telemonitoring, aimed at maximizing the quality of life of chronic patients by means of a regular collection of information about their status and actions in a long-stay setting. In this paper, a knowledge based decision support system is presented, which is aimed at aiding clinical professionals in managing chronic patients on a daily basis, by assessing their current status, helping face their worsening conditions, and preventing their exacerbation events.

Keywords: Decision Support, Knowledge Formalization, Ontology.

1 Introduction

Chronic diseases are generally characterized by complex and difficult prognosis and treatment, and experience, more or less frequently, exacerbation events that require patients' hospitalization. A key role in the management of chronic diseases is recently being assumed by smart systems specifically devised to constantly monitor patients for perceiving changes of their status and anticipating or detecting the occurrence of acute events to be treated. In particular, an effective and profitable solution for supporting the decisional processes cannot be limited to the gathering of patients' data via dedicated sensors, but it should also offer advanced facilities for analyzing such data in order to present only the most relevant information to clinicians without overwhelming their clinical activity.

According to these considerations, this paper proposes a knowledge-based *Clinical Decision Support System* (CDSS) for managing chronic patients by interpreting data acquired through a sensor infrastructure deployed in patients' normal life environment. This system combines acquired data with patients' clinical information, issues possible alarms and supplies motivated suggestions to clinicians. The application scenario was

K.S. Nikita et al. (Eds.): MobiHealth 2011, LNICST 83, pp. 38–45, 2012.

represented by two specific diseases, namely Chronic Obstructive Pulmonary Disease (COPD) and Chronic Kidney Disease (CKD), even if the approach can be applied, more in general, to any chronic disease.

The system was developed within the EU IST Project CHRONIOUS which is aimed at defining a generic platform schema for health status monitoring, addressed to and specialized for people suffering from chronic diseases [1]. In the following, the adopted strategy is detailed, presenting the CDSS design and describing implementation details and results achieved.

2 Clinical Decision Support System Design

The CDSS was designed to support the remote management of chronic patients by interpreting data collected via a sensing infrastructure, deployed to acquire a number of records about patients' disease signs, behavior, activity, and contextual situations. Such records are meant to assess, on a daily basis, patients' situation and, hence, follow up their response to therapy on a long period, verify that their life style is mostly correct, and identify the onset of possible disease exacerbations.

More precisely, a platform of services was designed to acquire, store and interpret these sensor data and alert clinicians whenever a worrying situation is detected. The platform comprises a sensing infrastructure which collects the following patient's data:

- disease signs and symptoms, collected by a sensorized vest able to record patients' (i) electrocardiographic and (ii) respiratory activities, (ii) arterial oxygen saturation, (iii) skin temperature, (iv) cough and snoring, (v) motion activity and fall. Commercially available devices are also employed for measuring (vi) body weight, (vii) blood pressure and (viii) blood glucose;
- contextual data, collected by an environmental device installed in patients' living room for acquiring information about (i) ambient light, the presence of (ii) carbon monoxide, (iii) volatile organic compound and (iv) air particle;
- patient's inputted data, collected through questionnaires proposed on a touch-screen workstation for acquiring information pertinent to (i) patients' lifestyle, (ii) food and (iii) drug intake, (iv) psychological conditions.

All these data are collected regularly and stored into the platform repository which is also used to stock patient's data collected during clinical visits (through external communications with clinical sites, according to HL7 medical standard).

For the interpretation of these data, in order to achieve a notable level of reliability and flexibility, two levels of intelligence were conceived: a first level of intelligence deployed on a *Personal Device Assistant* (PDA) is in charge of detecting changes of the patients' status by applying simple rules, only working on the acquired parameters. Whenever a significant alterations is detected, clinical staff is alerted and, contextually, a second level of intelligence, i.e. the CDSS, is invoked, since able to correlate a wider set of information pertaining the patient and provide more reliable and accurate answers.

Figure 1 summarized the main components of the whole monitoring platform (for more details about the entire platform, please refer to [2]).

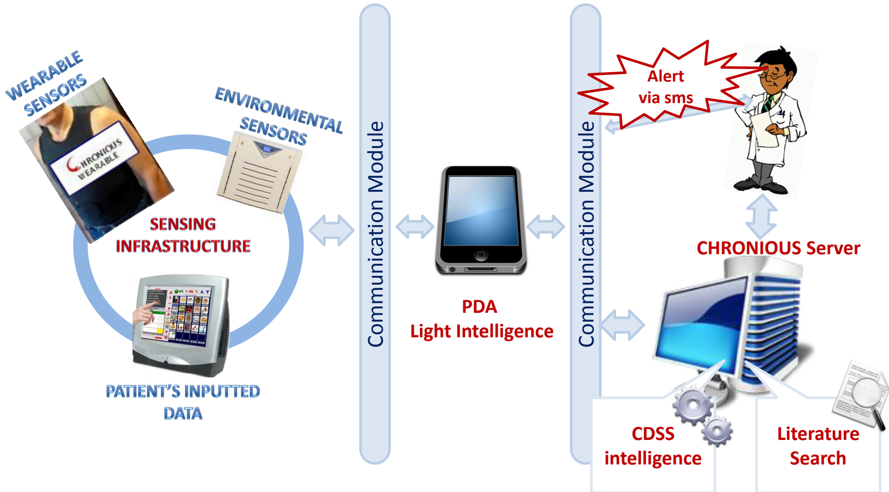

Fig. 1. The remote monitoring infrastructure: the Sensing Infrastructure with the different types of collected data and the two levels of intelligence for interpreting patient's collected data

As it often happens in the development of clinical support systems, a knowledge based approach was followed for developing the CDSS. However, differently from other clinical problems, the remote management of chronic patients is an emerging procedure, not yet well assessed. The clinical guidelines currently available provide clinicians with general instructions for disease diagnosis and treatment within the practice of clinical environment (see, e.g., COPD guidelines GOLD [3]). They do not contain any information about which parameters should be acquired for monitoring patients in their daily life, how these should be interpreted and how an exacerbation event could be identified.

Since some experiments of patients' telemonitoring are being carried out [4], the most viable solution appeared the elicitation of the pertinent knowledge directly from clinicians involved in such experimental activities. The CDSS Knowledge Base (KB) was then built by formalizing the knowledge brought forth by clinicians with specific expertise in telemedicine programs from the Fondazione Salvatore Maugeri for COPD, and from the University of Milan and the San Carlo Hospital in Milan for CKD.

The knowledge elicitation and formalization process is detailed in the next section; to make this process easier, a scenario based approach was adopted so as to better identify the CDSS interventions and three main scenarios were identified for invoking the data interpretation:

- an *Alarm Checking* scenario, for the assessment of patients' status after an alarm issued by the PDA due to a possible exacerbation detected;
- a *Home Monitoring* scenario, for a periodic assessment of patients' status (once a day), even without any alerting exacerbation;
- a *Clinical Assessment* scenario, for the evaluation of patients' status after a clinical visits.

In all these cases, according to the knowledge modeled into its KB, the CDSS first analyzes the received data and correlates them with historical patient's data and, then, alerts clinicians when an acute event happens, also providing suggestions about actions to be performed.

2.1 Knowledge Formalization

For the knowledge elicitation process, several meetings were carried out with clinicians for agreeing how all the information gathered inside the monitoring platform are correlated and can be interpreted to identify worrying conditions. A set of evidence-based statements resulted from this process; each of them relates a condition about the possible values of the acquired sensor data with a conclusion that can be drawn on patient's status. Knowledge contained into the available clinical guidelines, among them the GOLD [3] for COPD and the NKF-KDOQI-02 [5] for CKD, was also considered, especially for interpreting and relating data acquired during clinical visits.

The formalism selected for encoding all relevant knowledge was selected considering:

- the "*condition-conclusion*" form of the knowledge elicited from clinicians;
- the characteristic of such elicited knowledge to resemble not standard clinical procedures, but more a cross-analysis of patients' vital signs parameters aimed at assessing or predicting the occurrence of an acute event;
- the peculiarity of existing methods for modeling clinical guidelines which are, so far, only modeling methodologies, without a really working engine for running the encoded guidelines;
- the possibility to develop an application for allowing clinicians to upgrade the encoded knowledge.

These considerations fostered the selection of an encoding formalism based on *production rules*, i.e. a set of conditional statements expressed in form of "***if*** *antecedents* ***then*** *consequent*".

In order to make the KB interoperable and define a well assessed terminology for the KB, the production rules were defined on the top of an ontology. This contains all the information pertaining a chronic patient (i.e. medical history, patient general information, laboratory assays, patient monitoring measurements or environmental measurements gathered at the patient's home, questionnaires about mental problems or symptoms) and also the suggestions generated by the CDSS to be reported to the clinicians. The combination of ontology and rules consists in expressing rule antecedents and consequents by using concepts, properties and relations of the ontology. In particular, for making the rule writing process simpler, all the relevant parameters to be used were defined as concept properties (i.e., the *datatype* properties of the *Ontology Web Language* – OWL [6]). In deed, the use of concept relations (i.e., the *object* properties of OWL) would have required the specification of complex and scarcely intuitive chains of concepts and relations in the rule antecedents and consequents.

The ontology concepts were characterized by a well-specified semantics through axioms and restrictions, whereas properties have been defined in terms of domain, i.e. the admissible subject concept, and range, i.e. the admissible object concept or a value type. In more detail, concepts and properties was organized in two groups, named *Patient Situation* and *CDSS Suggestion*. This kept the ontology maintenance simpler and assured ontology easily reusability and extensibility. Both these groups of concepts were specialized by sub-concepts and/or properties.

In particular, the group named *Patient Situation* models a sort of synthetic clinical summary of chronic patient and includes all the information required to define the clinical situation of the patient, while being constantly and remotely monitored at home. Such information was further categorized under the main concept *PatientSituation* and placed into five sub-groups, named respectively *Clinical Information*, *Medical History*, *Monitoring Information*, *Patient General Information* and *Therapy Prescription*. These were further specialized as shown in Figure 2.a.

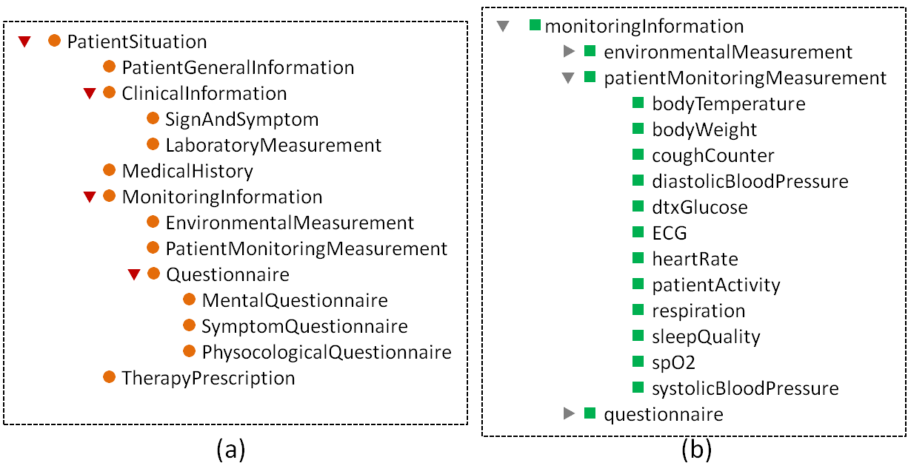

Fig. 2. (a) the taxonomy of concepts; (b) a fragment of the taxonomy of properties, in particular the properties of the *PatientMonitoringMeasurement* (when having the same name, concepts and properties are differentiated by uppercase and lowercase initial letter)

This group of concepts were specified by defining a number of properties, which correspond to each piece of information (i.e., patient's monitoring data, clinical visit data, patient's medical history, and so on) relevant for the CDSS KB. As an example, Figure 2.b reports all the properties associated to the concept *MonitoringInformation*.

The group *CDSS Suggestion* specifies the results of the inferences generated by the CDSS in terms of suggestions to be reported to the clinicians. Such suggestions were expressed in terms of alerts, i.e. messages with a different severity, varying in accordance with the current patient condition, that can require or not the attention of a clinical operator. In more detail, the group contains the concept *CDSS_Suggestion* and a set of properties which describe the CDSS outputs. More precisely, the defined properties are:

- *alertSeverity*, which indicates the severity the suggestion produced by CDSS has to be reported with, in order to appropriately alert a specific clinical operator, e.g. a nurse, a clinician or the emergency department of an hospital. Such a severity was formalized in terms of a color which can assume values in this set *{white, green, yellow, red}*;
- *patientStage*, which specifies the severity inferred by CDSS for each chronic disease (i.e. COPD and CKD). Such a severity is expressed in terms of stages, assuming values between 1 and 4 for COPD and 1 and 5 for CKD, in accordance with the guidelines for the COPD and CKD severity evaluation [3, 5];
- *patientCondition*, which indicates a variation of the health status of the patient with respect to the morbidity he/she is affected by. For example, it indicates a "*renal function worsening"* when the morbidity stage in a CKD patient is changed from 3 to 4, or an "*invariant renal function"* whenever the morbidity stage in a CKD patient remains stable.
- *guideline*, which describes in natural language the specific clinical guideline applied by CDSS to infer the corresponding suggestion;
- *suggestedAction*, which expresses the action which has to be performed in response to a determined suggestion generated by CDSS. Such an action should be reported either to the patient, when his/her condition is not critical, or to a clinical operator, whenever the situation is very critical for the patient.

Based on this ontology, production rules were devised for the three reported scenarios, representing, this way, actions and suggestions to be generated (i.e., the so called *procedural knowledge*).

Each rule is composed of one or more antecedents, expressed in terms of ontology properties concatenated by logical conjunctive operators, which can be evaluated to be either true or false. Disjunction was not supported. Moreover, each rule has exactly one conclusion, which can be an assignment to some parameters or a CDSS suggestion. Some simple rules, organized according to the reported structure, are reported in Table 1.

Table 1. Three examples of elicited rules

Antecedent	**Consequent**		
Description	Suggested Action	Patient's Condition	Alert Severity
systolicBloodPressure >140mmHg and spO2<95%	*Alert medical doctor*	*Fluid overload*	*Red*
diastolicBloodPressure >90mmHg and spO2<95%	*Alert medical doctor*	*Fluid overload*	*Red*
systolicBloodPressure<100 and heartRate>115 and nauseaOrVomiting='true'	*Doublecheck the alarm and alert immediately emergency medical service*	*Hypo-Volemia*	*Red*

3 Implementation and Results

The CDSS was modularly conceived and realized in order to be straightforwardly connected to any platform by using a service oriented approach. It was indeed structured as a set of decisional services which are called on demand when specific events occur, in accordance with the set of scenarios introduced in the previous section. These were implemented as two Web Services, named COPD*_Decisional_Service* and *CKD_Decisional_Service*, realized respectively for COPD and CKD diseases. Each service was delineated from a functional perspective in terms of its operations, where each operation is coarse-grained and models how the CDSS works for one of the identified scenarios.

For what concerns the KB, the ontology was developed using OWL [6] and currently, consists of 28 concepts and 860 properties. The rules were formalized in the Jena rule language [7], structured in scenarios and divided between the two pathologies: totally the base of rules contains 435 rules for CKD and 273 rules for COPD. Results provided by the CDSS consist in an advice about the status of the patient and a suggestion about the action to be undertaken for managing the situation. As an example, Figure 3 shows the results generated by *CKD_Decisional_Service* in terms of suggestions and explanations reported in response to abnormal values due to a condition of HypoVolemia. This is suitably displayed on a clinicians' graphical user interface developed into the platform of services, not pertaining only the work carried out for the CDSS implementation [2].

The system was tested for evaluating the performance of the Web Services; in particular both functional and load tests were performed by using SOAP-UI tool [7]. The system has been released and a validation phase is planned to start at the end of year.

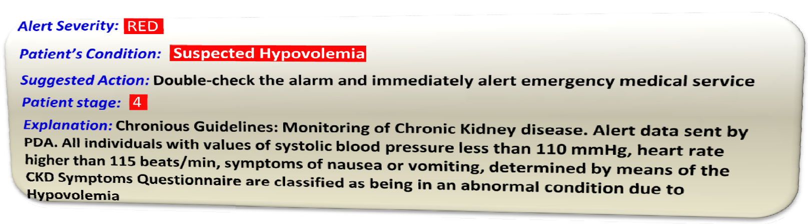

Fig. 3. Example of information suggested by the Clinical Decision Support System

4 Conclusions

A key role in the management of chronic diseases is covered by smart systems specifically devised to constantly monitor patients for perceiving changes of their status and anticipating or detecting the occurring of acute events to be treated. A great added value to these systems is the development of intelligent applications able to automatically interpret the acquired data.

In this frame, a Clinical Decision Support System has been presented in this paper, which is aimed at aiding clinical professionals in managing chronic patients on a daily basis, by analyzing sensor data for assessing patients' current status and presenting a more personalized advice and feedback to clinicians. The CDSS was developed by encoding the pertinent knowledge elicited from clinicians with a specific experience in patients' telemonitoring. A formalism based on one ontology and a base of rules was selected since the most suitable in terms of the form of elicited knowledge and the purposes of the system. The system was developed according to a scenario-based approach, implementing each identified scenario as a Web Service operation. This assures the interoperability of the system and the possibility to plug it into any monitoring platform of the same kind.

Currently, the CDSS has successfully passed the functional and load tests applied to the developed web services. A clinical testing process is planned to start at the end of the year within the EU project CHRONIOUS.

Acknowledgments. This work has been partly funded by the EC IST Project FP7-ICT-2007–1–216461 CHRONIOUS: http://www.chronious.eu/. The authors wish to acknowledge their gratitude and appreciation to all the project partners for the development of the ideas and concepts presented in this paper.

References

1. Rosso, R., Munaro, G., Salvetti, O., Colantonio, S., Ciancitto, F.: CHRONIOUS: an open, ubiquitous and adaptive chronic disease management platform for Chronic Obstructive Pulmonary Disease (COPD), Chronic Kidney Disease (CKD) and Renal Insufficiency. In: Armentano, R.L., Monzon, J.E., Hudson, D., Patton, J.L. (eds.) Proceedings of Annual Int. Conf. of the IEEE, EMBC 2010 - Engineering in Medicine and Biology, Buenos Aires, Argentina, August 31-September 4, pp. 6850–6853. IEEE (2010)
2. Lawo, M., Papadopoulos, A., Ciancitto, F., Dellaca, R.L., Munaro, G., Rosso, R.: An open, ubiquitous and adaptive chronic disease management platform. In: 2009 6th International Workshop on Wearable Micro and Nano Technologies for Personalized Health (pHealth), June 24-26, pp. 69–71 (2009)
3. Gold 2008. Global initiative for chronic obstructive lung disease. A collaborative project of the National Heart, Lung, and Blood Institute, National Institutes of Health, and the World Health Organization. Bethesda (2008), http://www.goldcopd.org
4. Vitacca, M., Bianchi, L., Guerra, A., Fracchia, C., Spanevello, A., Balbi, B., Scalvini, S.: Tele-assistance in chronic respiratory failure patients: a randomised clinical trial. Eur. Respir. J. 33, 411–418 (2009)
5. NKF-KDOQI-02 Clinical Practice Guidelines for Chronic Kidney Disease: Evaluation, Classification and Stratification (2002), http://www.kidney.org/professionals/kdoqi/guidelines_ckd/toc.htm
6. OWL (2009), http://www.w3.org/TR/owl-features/
7. Carroll, J.J., Dickinson, I., Dollin, C., Reynolds, D., Seaborne, A., Wilkinson, K.: Jena: implementing the semantic web recommendations. In: Proceedings of the 13th Int.l World Wide Web Conference on Alternate Track, pp. 74–83. ACM, New York (2004)
8. (2011), http://www.soapui.org/