An Intelligent and Integrated Platform for Supporting the Management of Chronic Heart Failure Patients

S Colantonio[1], D Conforti[2], M Martinelli[1], D Moroni[1],
F Perticone[3], O Salvetti[1], A Sciacqua[3]

[1]Institute of Information Science and Technologies - Italian National Research Council (CNR), Pisa, Italy
[2]University of Calabria, Cosenza, Italy
[3]Department of Cardiology, University Magna Graecia, Catanzaro, Italy

Abstract

Within the EUFP6 project HEARTFAID, an integrated platform of services is being developed to assist chronic heart failure stakeholders in their routine workflow and to provide an optimal management of heart failure patients, by exploiting the most advanced technologies, compliant to medical standards, advanced instruments for diagnostic data processing, and significant and up-to-date knowledge, suitably formalized. The core of the platform intelligence is represented by a Knowledge based Clinical Decision Support System, which is aimed at making more effective and efficient all the processes related to chronic heart failure patients' management. In this paper, the current results of the platform development are reported and discussed.

1. Introduction

Chronic heart failure (CHF) is a complex cardiovascular syndrome, very significant for incidence and prevalence, which would strong benefit from a suitably defined care management program, aimed at improving and personalizing health care by slowing down the progression of the disease, alleviating symptoms, reducing hospitalizations, and minimizing risk factors [1]. These benefits can be achieved by a complex clinical workflow that entails identifying, collecting, integrating and processing a huge and complete amount of biomedical data and information.

Some attempts to cope with the problem of CHF patients' management have consisted in the development of dedicated IT solutions such as automated guidelines systems [2], decision support systems [3], or Machine Learning methods for automated CHF diagnosis [4] or prognosis [5].

Within the European STREP project HEARTFAID (www.heartfaid.org), an integrated platform of services is being developed for assisting CHF stakeholders, in particular clinicians and general practitioners, in their routine workflow and in providing an optimal management of CHF patients. The platform has been designed by exploiting the most advanced technologies, compliant to medical standards, advanced instruments for diagnostic data processing, and significant and up-to-date knowledge opportunely formalized [6,7].

The main functionalities of the platform can be summarized as (i) patients' telemonitoring; (ii) timely and interactive access to patients' data; (iii) interpretation of diagnostic investigations; (iv) therapy planning. These mainly rely on the platform intelligence core represented by a *Knowledge based Clinical Decision Support System* which has been developed by integrating, in functionally advanced settings, (i) deductive knowledge, elicited from guidelines and medical experts; (ii) inductive knowledge, extracted by data mining techniques applied to significant piles of data; (iii) computational methods for the analysis and interpretation of diagnostic data. The main goal of the system is to assist, at decisional level, the CHF health care operators, by making more effective and efficient all the processes related to diagnosis, prognosis, therapy and healthcare personalization of CHF patients [8]. A significant scenario has been taken into consideration for the development. It mimicks an actual situation which covers the clinical course of a patient, already enrolled in HEARTFAID platform, who is continuously telemonitored.

In this paper, the main functionalities of HEARTFAID platform are firstly described, for then focusing on the main peculiarities of the CDSS. Current results obtained on the chosen scenario are finally reported and discussed.

2. Methods: HEARTFAID platform of services

HEARTFAID Platform of services (HFP) has been conceived for assisting CHF caregivers in their routine activities of providing an optimal CHF patients management. A deep investigation on the everyday practice of clinicians has been performed for identifying their real needs and, thus, the main functionalities that HFP should provide. In particular, the following issues have been considered relevant and necessary:

- the collection and storage of all the relevant biomedical data, coming from different and several sources, which are usually considered by clinician for making their decisions;
- the definition of a telemonitoring program of patients' relevant clinical parameters (signs and symptoms), which can help addressing the problem of early detecting their worsening and, then, prevent acute events such as *decompensation*. Decompensation refers to the heavy exacerbation of symptoms, such as dyspnea, venous engorgement, and pulmonary edema, which requires a prompt hospitalization to re-establish adequate perfusion and oxygen delivery to end organs by adequate therapeutic treatments;
- the development of dedicated methods for processing relevant diagnostic data, such signals and images, in order to improve the objectivity and reproducibility of their interpretation;
- the provision of decision making aid, which can help clinicians in combining a huge amount of data and avoid errors.

HFP has been, then, designed consisting of six main technological components able to provide the core platform services, i.e., patients' data storage and management, homecare data collection with connected alerting service, data analysis and interpretation, clinical decision-making support. More precisely, as shown in Fig. 1, there are:

- a *Case Report Form*, which is a web-based record for inserting, editing, storing and managing patients demographic and clinical data;
- a *Telemonitoring System*, which is devoted to the collection and storage of data acquired by means of homecare sensing infrastructure;
- an *Alert & Alarm System*, which is in charge of warning the responsible care givers about worsening of patients' conditions when detected by the interpretation of telemonitored parameters;
- *Signal & Image Analysis Toolkits*, which consist of methods developed for semi-automated analysis of diagnostic signals (e.g., ECG) and images (e.g., echocardiographic or magnetic resonance images);
- a *Clinical Decision Support System*, which is a knowledge base system devoted to interpreting patients' data, tuning platform services (e.g., telemonitoring) and providing pertinent suggestions;
- a *Web-based User Interface*, which provides the access to all the services of the platform.

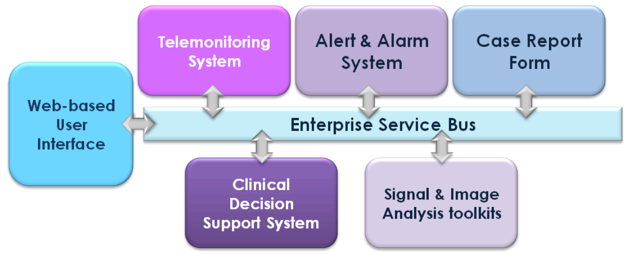

Fig. 1 HEARTFAID Platform and its main components

All these components are integrated by means of an *Enterprise Service Bus* (ESB), which serves for a loosely coupled, highly distributed and, thus, highly scalable integration network [9]. This means that all the platform components communicate among each other by exchanging messages on the ESB. Java, workflow and XML messaging based techniques have been selected for implementing the ESB [10].

The core of the platform is the CDSS which is involved in the main HFP services, at least in those that require intelligent or knowledge-based interpretation of data.

2.2. HEARTFAID decision support system

HEARTFAID CDSS has been conceived for processing patients' related information according to the relevant medical knowledge. The starting point of its development has been the identification of problems that clinical practitioners usually have to face and that can benefit from the intervention of a computerized support. This has been done in strict cooperation with the clinical partners of the project consortium. More precisely, the following CDSS interventions have been envisaged and planned for development:

- detecting worsening conditions issuing an alarm by interpreting telemonitored data;
- issuing suggestions for clinicians about (i) CHF etiology and nature; (ii) CHF severity degree (i.e. the *NYHA class* [1]); (iii) diagnostic investigations to be performed, and interpreting their findings; (iv) the most suitable therapeutic plan or changes to current plans; (v) a prognosis hypothesis.

From a careful investigation about the corpus of knowledge necessary for implementing the CDSS, experts' know-how and clinical guidelines have turned out as the main sources of knowledge. A *symbolic representation paradigm* has been then selected as formalization method and *Semantic Web Technologies*

(SWT) have appeared as viable instruments for implementing the corresponding *Knowledge Base* (KB). Currently, there is a strong interest on SWT in the clinical decision support community, as testified, first of all, by the rise of several ontology-like formalizations of medical domain, e.g. the *Systematized Nomenclature of Medicine* (SNOMED) [11], the *Unified Medical Language System* (UMLS) [12] or the *Medical Subject Heading* (MeSH) [13], to name a few. Moreover, a number of systems has been developed by using SWT, e.g. for assisting decision support in breast cancer management [14], or for modeling clinical practice guidelines [15].

Ontologies extended with rules have been, then, selected for formalizing the main explicit, declarative and procedural knowledge of the domain [16], [17]. However, some problems, such as prognosis stratification and the detection of patients' decompensation, seem still debated in the medical community, due to the lack of validated and assessed evidences and procedures. In these cases, experts' know-how can be only partially formalizing into a symbolic, inductive KB and should be integrated with *computational reasoning models* developed by applying *Machine Learning* techniques to deduce novel knowledge from relevant datasets.

According to these considerations, HEARTFAID CDSS was designed for incorporating different reasoning models and according to a multilevel conceptualization scheme for distinguishing among (i) the *knowledge level*, corresponding to all the information needed by the system for performing its tasks, (e.g. data, domain knowledge, computational decision models); (ii) the *processing level*, consisting of the system components that are responsible of tasks accomplishment by using the knowledge level; (iii) the *end-user application level*, including the system components whose functionalities are specifically defined for interacting with the user [3]. This separation assures a high level of flexibility, since any change of the formalized knowledge will not affect the processing level.In detail, the CDSS architecture consists of the following components:

- a *Domain Knowledge Base*, consisting of the domain knowledge, formalized from the European guidelines for the diagnosis and treatment of CHF and the clinicians' know-how;
- a *Model Base*, containing the computational decision models, signals and images processing methods and pattern searching procedures;
- a *Meta Knowledge Base*, composed by the strategy knowledge about the organization of CDSS tasks;
- the *Brain*, the system component endowed with reasoning capabilities.

In particular, the Brain has been modeled by functionally separating a *meta level*, devoted to task accomplishment and organization, and an *object level*, responsible for actually performing tasks, by reasoning on the computational and domain knowledge. A *Strategy Controller* has been inserted for performing the *meta level* functionalities, by orchestrating the two components of the object level, i.e. the *Inference Engine* and the *Model Manager*. When a request is committed to the CDSS, the Strategy Controller, according to what stated in the Meta Knowledge Base, requires the application of the Inference Engine or of the Model Manager. For difficult decisional problems, both inferential and computational reasoning methods can be applied and, thus, the Strategy Controller is responsible for the integration of their results.

3. Results

A real scenario has been detailed and considered as basis for the development of the CDSS. Such a scenario entails the main steps of the patients' management workflow, leading from visit scheduling to therapeutic choices, and involves the different care operators, e.g., clinicians, sonographers, laboratory analysts.

Implementing the scenario has required the formalization of the relevant domain knowledge and the development of computational models for processing diagnostic data and interpreting monitored data. The main functionalities of the other involved HFP components have been set up as well.

The first step in the development of the KB has been the development of the CHF ontology, which presents the formalized description of concepts for the whole heart failure domain [6]. It includes basic CHF concepts, patients' properties, all relevant diagnostic examinations and tests, and treatment procedures. CHF ontology provides a formalization of the declarative knowledge of the domain and has been developed in accordance to standard medical ontologies, such as UMLS. Specific concepts have been considered for the telemonitored measurements, i.e., signs and symptoms.

Production rules have been defined for formalizing the procedural knowledge and filling the logical lacks of ontological axioms. They were extracted from the ESC guidelines and elicited from clinicians. Examples of rules elicited in natural language are reported in Table I.

Knowledge discovery techniques have been applied to suitably collected datasets in order to define computational reasoning models able to predict patient's worsening and prevent a decompensation event. The symbolic KB and the computational Model Base have been integrating into the CDSS according to a service oriented approach. Currently, the CDSS meta-level has been bypassed and the application of the inferential reasoning as well as of a computational reasoning model has been encapsulated into web services described in WSDL. Algorithms for processing diagnostic data such as ECG and Echo images have been developed and included into a dedicated Model Base [19].

A web-based user interface has been developed for allowing the end users, i.e., patients and clinicians, to access the HPF services. In particular, a "user" ontology has been defined for managing users' authentication, while the interface has been tuned on the specific needs of different types of users. Fig. 2 shows the web-page displayed to clinicians for having a quick look at patients' status and current situations.

Table I. Some rules pertaining telemonitoring and drug assignment, formalized in natural language

Rules in natural language
If Heart Rate differs of 10% from the previous measurement **then** an alert should be issued
If a patient has Left Ventricle Ejection Fraction <= 40% **and** he is asymptomatic **and** is assuming ACE Inhibitors or ARB **and** he had a myocardial infarction **then** a suggestion for the doctor is to give the patient Betablockers

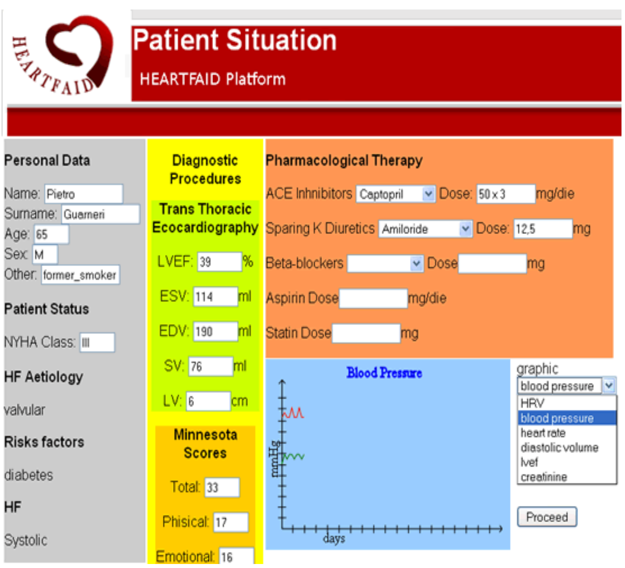

Fig. 2. The web page that pertains the clinicians' context for monitoring patients' situation

4. Discussion and conclusions

The paper presents the platform of services which is being developed within the EU project HEARTFAID for aiding CHF operators in their activity of care delivery and personalization. The main functionalities of the platform have been introduced and their implementation according to a web services approach has been delineated. The platform is going to be released to the medical partners, at the beginning of October, for a test and validation activity that will prove its effectiveness and usefulness in practice.

Acknowledgements

This work was partially supported by European Project HEARTFAID (IST-2005-027107).

References

[1] Swedberg K, *et al.* Guidelines for the diagnosis and treatment of Chronic Heart Failure: full text (update 2005). European Heart J 2005; 45 pages.

[2] Purin B, Rigo M, Riccadonna S, Forti S. An Interactive Real-Time Visualization Environment for Patients with Heart Failure. In: Proc. AMIA Annual Symp. 2005; 2005:1088

[3] Perlini S, *et al.*Treatment of chronic heart failure: an expert system advisor for general practitioners. Acta Cardiol. 1990; 45(5):365-78.

[4] Long WJ. Temporal Reasoning for Diagnosis in a Causal Probabilistic Knowledge Base. AIM 1996; 8:193-215.

[5] Atienza F, *et al.* Risk Stratification in Heart Failure Using Artificial Neural Network. In: Proc. of AMIA Annual Fall Sym 2000. 2000:32–6.

[6] Colantonio S, Martinelli M, *et al*. An approach to decision support in heart failure. In: Proc. of SWAP 2007. Bari, 2007:160-169.

[7] Colantonio S, Martinelli M, *et al*. Decision Support and Image & Signal Analysis in Heart Failure. In: Proc. of HEALTHINF. Madeira, 2008:288-295.

[8] Colantonio S, Martinelli M, *et al*. A Decision Support Resource as a Kernel of a Semantic Web based Platform oriented to Heart Failure. In: Proc. of SWWS'08. LasVegas, 2008.

[9] Chappell D. Enterprise Service Bus. O'Reilly 2004.

[10] Di Bona S, *et al.* Integration and Interoperability middleware prototype. Deliverable D28, HEARTFAID IST-2005-027107, 2007.

[11] SNOMED www.snomed.org/

[12] UMLS http://www.nlm.nih.gov/research/umls/

[13] MeSH http://www.nlm.nih.gov/mesh/

[14] Dasmahapatra S, *et al.* Ontology-Based Decision Support for Multidisciplinary Management of Breast Cancer. In: Proc. of Int. Ws. on Digital Mammography. 2004.

[15] Martinelli M, Salvetti O, Little S, Asirelli P. Algorithm representation. Multimedia Annotation Interoperability Frmw. W3C Multimedia Semantics Incubator Gr. 2006.

[16] Asirelli P, Martinelli M, Salvetti O. Call for a common multimedia ontology framework requirements. In: Towards a Common Multimedia Ontology Framework, Acemedia. 2006:1-5.

[17] Hussain S, Raza Abidi S. Semantic Web Framework for Knowledge-Centric Clinical Decision Support Systems. LNCS Springer 2007; 4594:451-455.

[18] Chiarugi F, Colantonio S, *et al.* ECG and Echocardiography Processing for Decision Support in Heart Failure. In: Proc. of Computers in Cardiology 2008.

Address for correspondence
Name Ovidio Salvetti
Full postal address: Via Moruzzi 1, 56123, Pisa (Pi), Italy
E-mail address: ovidio.salvetti@isti.cnr.it