Specialist Decision Support for Patients with Ventricular Assist Devices

M.G. Tsipouras, A.T. Tzallas, E.C. Karvounis,
Biomedical Research Institute – FORTH
Ioannina, Greece
Unit of Medical Technology and Intelligent Information Systems, Dept. of Material Science & Engineering,
University of Ioannina
Ioannina, Greece
markos@cs.uoi.gr, atzallas@cc.uoi.gr, ekarvouni@cc.uoi.gr

N.S. Katertsidis,Y. Goletsis, K. Stefanou, D.I. Fotiadis
Biomedical Research Institute – FORTH
Ioannina, Greece
Unit of Medical Technology and Intelligent Information Systems, Dept. of Material Science & Engineering,
University of Ioannina
Ioannina, Greece
nkaterts@cc.uoi.gr, goletsis@cc.uoi.gr, kstefan@cc.uoi.gr, fotiadis@cs.uoi.gr

J. Terrovitis
3rd Cardiology Department, School of Medicine University of Athens
Athens, Greece
john.terrovitis@gmail.com

M.G. Trivella
Istituto di Fisiologia Clinica-CNR
Pisa, Italy
trivella@ifc.cnr.it

Abstract—**This work presents the Specialist's Decision Support System (SDSS), which is one of the main components of the SensorART platform. SensorART focuses on the management and remote treatment of patients which suffer from heart failure and are treated with ventricular assist devices (VADs). SDSS is a Web-based application that assists specialists on patient's management, offering a plethora of tools for monitoring, designing the best therapy plan, analyzing data, extracting new knowledge and making informative decisions.**

Keywords-Ventricular assist devices; decision support system; web aplications

I. INTRODUCTION

Heart failure (HF) is an inability of the heart to fill with enough blood or pump with enough force or both the human body. It develops over time as the pumping action of the heart grows weaker and can affect the left side and/or the right side of the heart. The most common causes of HF include: high blood pressure (hypertension), coronary heart disease, heart valve disease, and cardiomyopathy. HF is the most increasing cause of death in developed countries; approximately 2% of the adult population suffers from HF, although it mainly affects elderly people (6-10% of people over the age of 65 years will develop HF) [1]. Hence, together with the difficulty of having a sufficient number of donor organs, it is recognized that the VADs will assume an increasingly important role in treating the growing number of patients with advanced HF, not only as bridge to transplant, but also as destination therapy, by considering also the ageing population.

Over the past three decades, technological advancements have led to the development of a series of implantable and external VADs for patients of every age and body size. However, most of these commercial VADs still share a common drawback. They do not provide to the specialists remote monitoring and/or controlling possibilities. The patient must visit the hospital, in order for the specialist to assess his/her condition. Continuous automatic remote monitoring systems and database systems are in the early stage of development with only a few relevant research studies reported [2-5].

SensorART aims to provide a set of technologies for heart assistance, supporting patients with chronic HF, treated at home without renouncing to access high medical expertise, and healthcare specialists keeping under control the performance of cardiovascular implanted VAD by remote control services. This platform moves from the concept of realizing an "upgraded device", thus starting from a VAD that is a mechanical device with the plan of developing an intelligent device.

In general, the SensorART platform consists of five main parts: (i) Sensor component, (ii) Signal Acquisition component, (iii) Hardware Controller, (iv) Remote Control Framework, and (v) Specialist's Decision Support System (SDSS), which is described in this paper. SDSS assists the specialists on deciding the best treatment strategy for a specific patient. It includes: a VAD-heart simulation component that gives to the specialists the possibility of modeling the behavior of a patient before and after VAD implantation, as well as a Decision Support System providing data analysis and projection tools.

II. SDSS PLATFORM

The SensorART SDSS is a Web-based platform that enables specialists with advanced data-driven and expert-knowledge techniques, in order to effectively assess and exploit real patient data (from the Specialist's Monitoring Application), as well as simulated patient data (from the VAD-Heart Simulation Platform) through the following components: (i) Knowledge Discovery, (ii) Monitoring, (iii) Treatment, (iv) Weaning, (v) VAD Suction, and (vi) VAD Speed. The modules menu in the SensorART Web-platform is presented in Fig. 1.

 ISBN: 978-1-61208-252-3

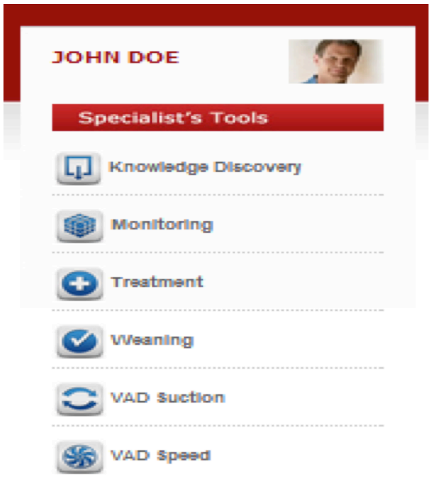

Figure 1. Specialist's Tools menu in the SensorART platform.

A. Knowledge Discovery

The knowledge discovery module includes two sub-modules; the association rules tool and the statistics tool.

1) Association Rules Tool: The Association Rules Tool allows the extraction of association rules from the database, enabling thus the extraction of new knowledge from multiple and heterogeneous archived data. The procedure depends on the patients selection, the examined features, the observation period and the support/confidence for the rule mining technique, which is the the *Apriori* algorithm [7]. All the above are defined from the specialist, who: (i) selects some or all patients from the database, (ii) defines the features (and, if needed, corresponding threshold values) to be examined, (iii) sets an observation period and appropriate values for support and confidence. Based on the above selections, associations hidden in the data are derived in the form of "if – then" rules, with the features (variables from the database) and conditions in the "if" and "then" parts defined by the user. The features that can be selected are categorized as: (i) demographic – comorbidities, (ii) heart related, (iii) sensor related, and (iv) laboratory measurements. The outcome of the Association Rule Tool is presented in Fig. 2.

2) Statistics Tool: The statistics tool provides all the necessary tools for the analysis and interpretation of patient data through powerful statistical techniques. These include descriptive statistics (mean, standard deviation, median, variance) along with statistical functions such as hypothesis testing (one Sample and two-Sample *t*-test, pair-sample *t*-test, Welch corrected *t*-test), analysis of variance (ANOVA), nonparametric tests (Kruskal-Wallis ANOVA, Wilcoxon test for one sample and paired Sample) and survival analysis (Kaplan-Meier estimator). A sample for the Kaplan-Meier survival analysis is presented in Fig. 3.

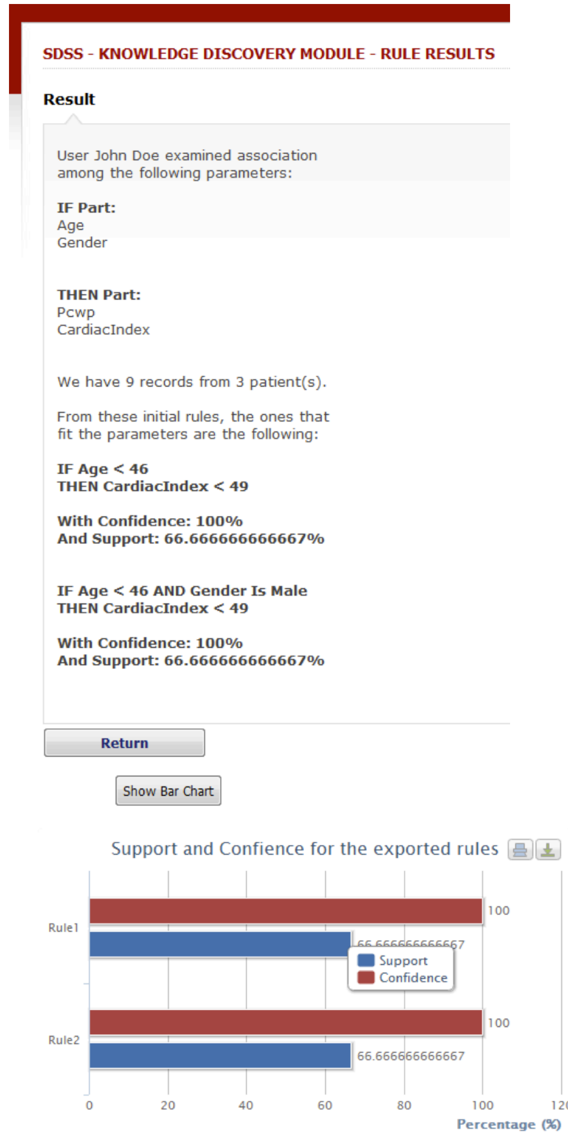

Figure 2. Association Rules Tool outcome.

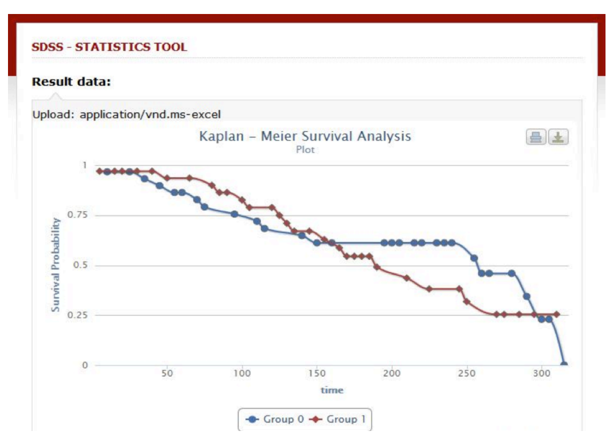

Figure 3. Kaplan-Meier survival analysis from the statistics tool.

 ISBN: 978-1-61208-252-3

B. Monitoring

The monitoring module provides a graphical tool for examining the day-to-day VAD and patient parameters along with any adverse events that may have occurred. The patient and the parameters that will be included in the graph are selected by the specialist. The features that can be selected are: pump flow/speed/power, pulse index, temperature, systolic and diastolic blood pressure, pulses, weight, INR and drug dosage (warfarin/acenocoumarin), while the adverse events that are recorded include: death, cerebral bleeding, gastrointestinal bleeding, ischemic stroke, transient ischemic attack, ventricular tachycardia and heart failure. A snapshot of the patient and parameters selection along with the graphical result of the monitoring module is presented in Fig. 4.

Furthermore, the Monitoring module is able to provide assessment for future adverse events appearance. The main idea is to analyze the day-to-day data for the last three days and assess the possibility of adverse event appearance in the next day. Subsequently, the functionality is available only if data for the last three days exist. The assessment model has been developed using data from the SensorART database in order to train a decision tree. Currently data from 8 patients, that generate 1026 prototypes have been used for the decision tree induction, however, the model is constantly updated as new data are stored in the database (i.e. retained with larger datasets).

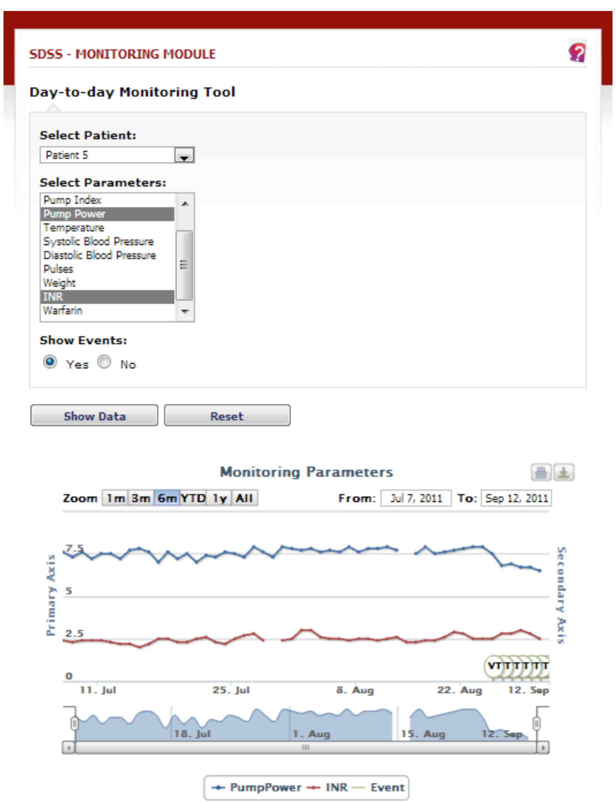

Figure 4. Monitoring module outcome.

C. Treatment

The treatment module can provide risk analysis based on known risk scores, in order to support effective treatment of patients. These include:

- the Heart Failure Survival Score (HFSS),
- the Seattle Heart Failure Model (SHFM),
- the Model for End-Stage Liver Disease (MELD) (due to its potential prediction on survival and need for blood transfusion),
- the Right Ventricular Failure Risk Score (RVFRS) to predict right failure that constitutes a serious complication.

D. Weaning

The Weaning module combines expert knowledge with fuzzy modeling, in order to support the specialists in the selection of patients that may be removed from the VAD therapy. The main idea is to achieve a mixture-of-experts approach, in terms of having multiple models for weaning in the module. These include all state-of-the-art medical knowledge-based models presented in the literature. In addition, the specialist can create and modify additional models (collection of if-then rules), using the build-in model generator. Furthermore, the module incorporates an automated fuzzy model generator [8], aiming on an efficient way of automatically transforming crisp models (either from the literature or user-defined) into fuzzy ones.

The knowledge-based models that have been included from the literature are the ones presented by Santelices et al. [9] and Birks et al. [10]. The user can either view or execute one of the existing models or create a new one, which is subsequently added in the list of existing models and can be also viewed/executed. Also, the user can modify all user-defined models, but not the ones from the literature. A snapshot of the view/execute model screen is presented in Fig. 5.

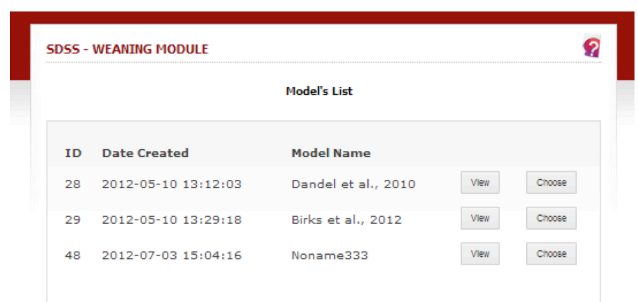

Figure 5. Model selection in the Weaning module.

E. VAD Suction

The VAD suction module provides to the specialists a powerful assistant in their attempt to effectively analyze their simulation sessions from the VAD-Heart Simulation Platform in terms of the suction phenomenon. Used in combination with the VAD-Heart Simulation Platform, it enables specialists to further analyses data from simulation sessions recognizing suction events (Fig. 6).

 ISBN: 978-1-61208-252-3

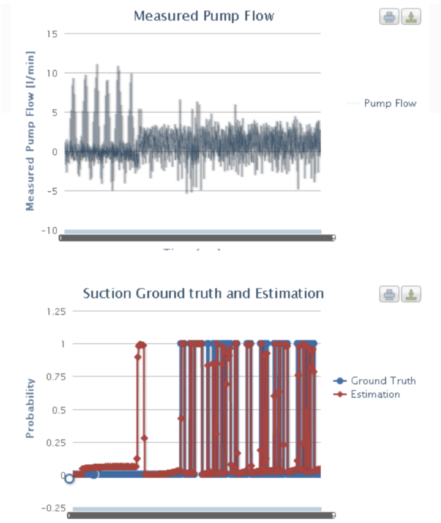

Figure 6. Visual representation of suction module results.

F. VAD Speed

The VAD speed module provides to the specialists a powerful assistant in their attempt to effectively plan the treatment strategy for a patient. It proposes adjustments to pump speed settings according to the required cardiac output and pressure perfusion. Used in combination with the VAD-Heart Simulation Platform and VAD suction module, it enables specialists to further analyse data from simulation sessions, identify different pump states and possible issues, as well as draw conclusions regarding the most appropriate pump speed settings.

III. CONLUSION

In this paper, the SDSS platform of the SensorART project is presented and all major tools and functionalities are illustrated. The SDSS has been specifically designed with close collaboration with medical experts, in order to address all major issues and provide all necessary tools for specialists treating VAD patients, in a single platform. In the same context, it includes all medical models and all available medical knowledge regarding VADs and patients with VADs. However, instead of being just a simple collection of medical and technical knowledge, in SDSS these are harmonically merged with computational intelligence, data mining and fuzzy modeling techniques, along with the first specially built database for VAD patients, thus leading to a powerful tool that can support specialists to any decision needed regarding the optimal management of VAD patients.

ACKNOWLEDGMENTS

This study is partially supported by the SensorART project ("A remote controlled Sensorized ARTificial heart enabling patients empowerment and new therapy approaches", FP7-248763).

REFERENCES

[1] J. J. McMurray and M. A. Pfeffer, "Heart failure," Lancet, vol. 365(9474), pp. 1877–1889, 2005.

[2] E. Okamoto, E. Iwazawa, S. Suzuki, S. Fukuoka, and Y. Mitamura, "Feasibility of a remote monitoring system for patients with an implantable left ventricular assist device using Personal Handy-Phone System telecommunication technology," J. Artif. Organs, vol. 4(3), pp. 172–179, 2001.

[3] R. Kosaka, Y. Sankai, R. Takiya, T. Jikuya, T. Yamane, and T. Tsutsui, "Tsukuba Remote Monitoring System for Continuous-Flow Artificial Heart," Artif. Organs, vol. 27(10), pp. 897–906, 2003.

[4] J. Chung, J. H. Lee, J. Choi, J. Lee, W. G. Kim, K. Sun, and B. G. Min, "Home care artificial heart monitoring system via internet," Int. J. Artif. Organs, vol. 27(10), pp. 898–903, 2004.

[5] J. Choi, J. W. Park, J. Chung, and B. G. Min, "An intelligent remote monitoring system for artificial heart," IEEE Trans. Inf. Technol. Biomed., vol. 9(4), pp. 564–573, 2005.

[6] K. W. Nam, J. J. Lee, C. M. Hwang, S. W. Choi, H. S. Son, and K. Sun, "Personal digital assistant-based, internet-enabled remote communication system for a wearable pneumatic biventricular assist device," Artif. Organs, vol. 31(11), pp. 842–845, 2007.

[7] R. Agrawal and R. Srikant. "Fast algorithms for mining association rules in large databases," Proc. 20th Int. Conf. Very Large Data Bases, Sept. 1994, pp. 487-499.

[8] M. G. Tsipouras, T. P. Exarchos, and D. I. Fotiadis, "A methodology for automated fuzzy model generation," Fuzzy Sets and Systems, vol. 159(23), pp. 3201-3220, 2008.

[9] L. C. Santelices, Y. Wang, D. Severyn, M. J. Druzdzel, R. L. Kormos, and J. F. Antaki, "Development of a Hybrid Decision Support Model for Optimal Ventricular Assist Device Weaning," Ann Thorac Surg 90 (2010), 713-720.

[10] E. J. Birks, R. S. George, and M. Hedger, T. Bahrami, C. T. Bowles, C. Webb, R. Bougard, M. Amrani, M. H. Yacoub, G. Dreyfus, and A. Khaghani, "Reversal of severe heart failure with a continuous-flow left ventricular assist device and pharmacological therapy: a prospective study," Circulation, vol. 123, pp. 381-390, 2011.

