ECG Modeling by 3D Visual Membrane Petri Nets

Aurelia PROFIR, Roman DAMASCHIN, Laura PREPELITA
State University of Moldova
aureliaprofir@yahoo.com, shandor1988@yahoo.com, lauritta1992@yahoo.com

***Abstract* —We propose a 3D visual membrane Petri nets model of 1, 2, 3-leads *electrocardiogram* (*ECG*). This model is a part of the integrated Patient-specific model created by 3D VMPN software tool. Examples of 1, 2, 3-leads ECG are obtained. Our Patient-specific model is a computational model for investigation of the relevant aspects of compensatory physiological mechanisms, which evolve in the cardiovascular system and vital organs as well as peripheral blood circulation.**

***Index Terms* — animated simulation, ECG, Patient- Specific modeling, Petri Nets, 3D membranes.**

I. INTRODUCTION

In the Artificial Intelligence area, a special compartment is represented by the development of predictive models for personalized medicine, the development of individual treatments based on them and the development applications for elaboration, validation and runing models of visual membrane Petri nets models. Applicability of these models is related to the biomedical and pharmaceutical fields.

Within the project "Virtual Physiological Human", an application, called 3D Visual Membrane Petri Nets (3D VMPN), have been elaborated (see Fig. 1). This extensions of Petri nets has been elaborated using the concept of P systems [1] proposed by Gheorghe Paun and the theory of Petri Nets [2].

The developed application allows creating, validating and running of MPN models of pato-physiological compensatory mechanisms involved in the early stages of the type 1 and type 2 diabetes and cardiovascular diseases [3].

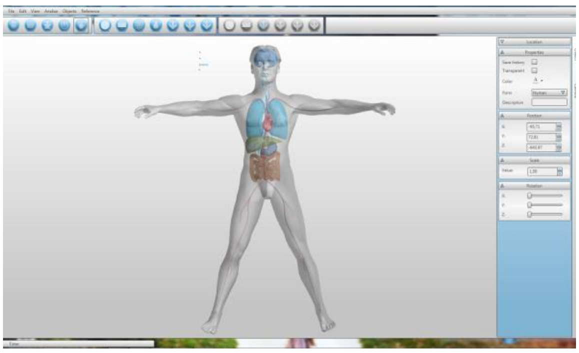

Fig. 1. Screenshot of the main window of the 3D VMPN aplication.

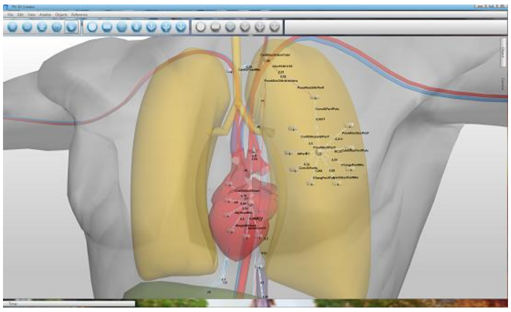

Fig. 2. Screenshot of the Patient specific model (heart and lungs), elaborated by the 3D VMPN application.

In section II some features of the 3D VMPN application is described. Section III is a summary description of the ECG representation of cardiac circle. In section IV the simulation results are shown.

II. MODELLING TOOL

The theory of the Petri nets, membrane calculations and P-systems are always developed, it had been already created a lot of applications allowing to build and simulate some models, but there are two questions here: are such models convenient at work and is the simulation fast? All previous versions of such applications allowed to create models, using 2D geometry primitives and the algorithms of simulation were lineal. Today, when the multi-core processors are widespread, it is not clever to create the lineal algorithms, which use only one processor. As for models, surely, it would be much more convenient if they could work as real systems, looking at them as if they are on the workplace. For this purpose it's necessary to use not only 3D geometry primitives, but some other 3D objects having any appearance you want. The new application called MPN 3D Builder suggests all these features, including powerful instrument of analyzing data (including tables of values and chart builders) gained from the simulation, improved formula builder, possibility to create models declaratively using special language, and an instrument of importing .3ds files which contains 3D objects created by some 3D editors.

For developing the graphic part of the 3D VMPN application the newest and the most effective technology such as Windows Presentation Foundation (WPF) [4] has been used. It is a graphical subsystem for rendering user interfaces which utilizes DirectX. The Parallel Extensions and Task Parallel Library (PE & TPL) [5] is used to synchronize and co-ordinate the execution of concurrent tasks improving performance of the algorithms for simulation. But all of them were created not only for improving the models appearance, because all objects of a model "become alive" at the simulation time.

This means that at the real-time it can be observed the form transformation of the objects, data transferring between the objects, motion of the objects at some different points of the space and all changes are happened according the speed of animation of each object.

Also during the simulation process the user can interact with camera and move between objects or membranes to watch what's happening inside of them. All of these create an impression of working with a real system, but at the same time don't forget, that the main purpose of these models is the receiving data after the simulation for researching, but not only to create the model which apparently would copy a real system.

So let's take a look at the application closer. The main window contains the main toolbar with all available objects, menu, model constructor, mini-toolbar for some manipulations with the model and status bar. An object properties panel is situated at the right side of the screen.

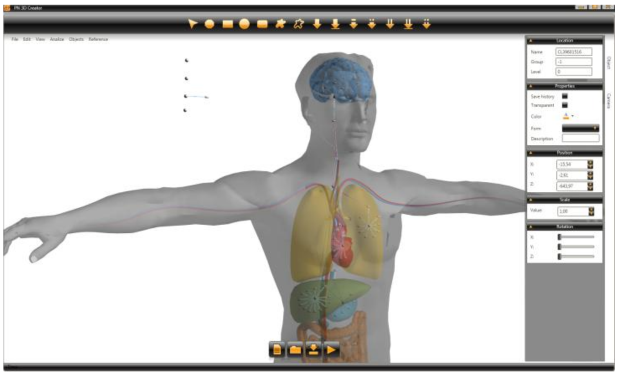

Fig. 3. The main window of the 3D VMPN application.

The constructor allows to create models by mouse-click adding objects at any place you point, but also there is a possibility to create models declaratively utilizing so-called ODL (Object Description Language) which is similar with XML syntax, but with some improvements.

The constructor and ODL Editor are connected reflectively and any object added via the constructor will be pasted at the code of ODL and conversely. Each object, of course, can be moved, scaled, rotated. Also there is a possibility to change appearance of all objects (color, form, etc.).

Fig. 4. ODL Editor

When a model was built some initial parameters for the objects, for example, default values, math expressions, formulas, etc. can be set. For this option it can be used the Object Properties Panel, but if the model is large it's not so convenient and it's better to use Model Configurator. It contains all properties for all kinds of objects and a table with objects which can be found by name or some other parameters.

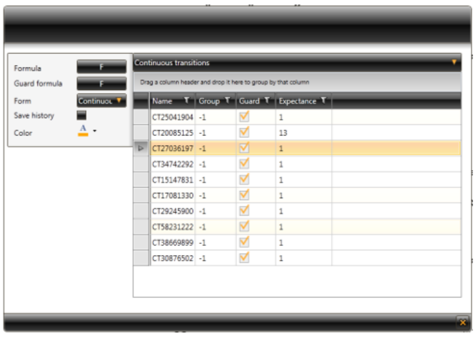

Fig. 5. Model Configurator

As it has been already mentioned, the math expressions for the certain values of objects that can be set.

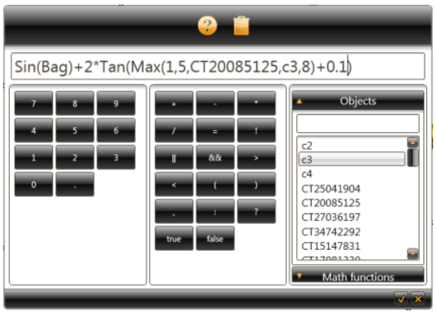

Fig. 6. Formula builder

The Formula Builder is a very powerful and very important tool here because with its help values can be changed dynamically. It contains a lot of standard math functions including some additional ones (Min, Max, etc.). Its main function is to compile the expression and return calculated value. As was already mentioned, an expression can use property values of objects (for example, for a discrete locations such value is tokens quantity, for a discrete transition - delay time, etc.). So if you attach a formula for the chosen object, for example, let it be a discrete transition, the delay time of this transition will be changed at each step of the simulation according this formula. When the simulation is run, the formula accepts values from all objects in each iteration which are contained in it (if they are there of course) and according to these values it is calculated and returned a new value.

So when the initial data are set up the model can be simulated. There are two kinds of the simulation: with animation (it means that users can watch simulation process step by step, including changing behavior, size and form of each object) and without animation (it means that users cannot watch the simulation process and they can receive only some results of the simulation).

As a result of the simulation we obtain diagrammes and data which show the evolution of themodelled processes in certain initial conditions given. With the help of formulas we build this model, showing real quantities, relations between organs and parts of organs, interactions. All this theoretical data it is taken from scientific researches of years and years of hard work of specialists in this domain (cardiology) and it is proved.

III. ECG REPRESENTATION OF CARDIAC CYCLE

Using the 3D VMPN application, a basic component of which is a 3D membrane structure, a model of ECG representation as a part of the Patient specific model has elaborated. The 3D membranes offer graphical representation of human body and organs (brain, heart, gastrointestinal system, liver, kidneys). There are 2 types of membranes: static and dynamic (for example, heartbeats are modeled with dynamic membrane represented the heart).

It is known that in the periods of depolarization and repolarization, the heart generates electrical currents, which can be detected and registered. This electrical activity generated by the heart muscle cells during the contraction of atria and ventricles can be measured by some electrodes placed on the body surface. The recorded tracing is called an electrocardiogram.

There are 12 ECG leads: 6 in the frontal plane and 6 in the transverse plane [6].

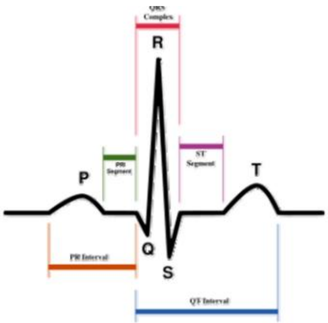

Fig. 7. ECG representation of cardiac cycle (lead I).

ECG representation of every cardiac cycle contains:

-waves: P, Q, R, S, T and U (positive or negative deflections).

-segments: the portions between waves.

-intervals: include segments and waves.

ECG is represented in standard conditions, with the amplitude 1mm=0.1mV and duration 1mm=0.04s

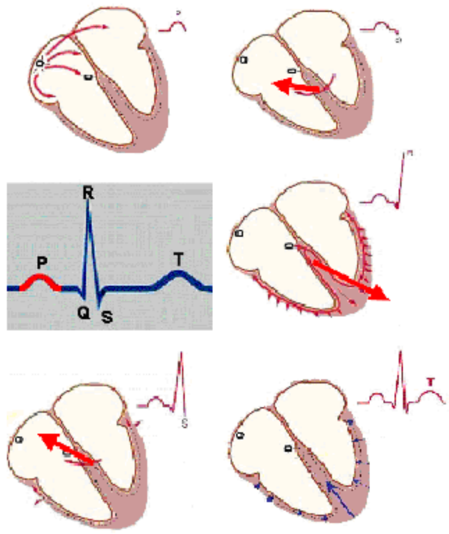

Fig. 8. On the drawings can be seen the resulting vectors, corresponding to waves that are recorded in the ECG (lead I) [7].

Projections of these vectors will be different for other leads and respectively leads for ECG recordings 2 -12 will look different.

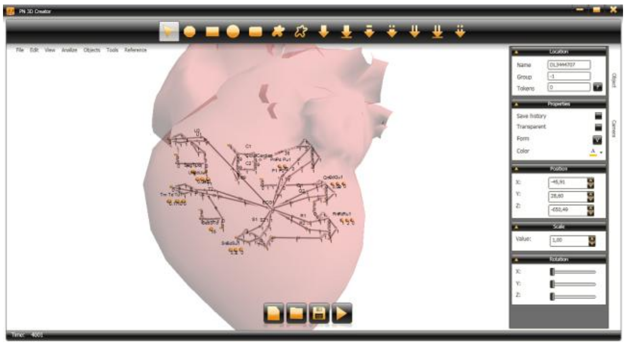

Fig. 9. Screenshot of the 3D VMPN model of ECG DI - DIII, a part of the 3D Patient specific model

IV. SIMULATION RESULTS

At registering the ECG, electrodes are placed on different parts of the body. In the first 3 frontal leads they are positioned on two arms and the left leg, thus forming a triangle where the heart electrically constitutes the null point. Our model reflects registering of ECG for lead I, II and III in the frontal plane.

So, the simulation results shown in Fig. 10 – 12 correspond to the results obtained in clinical practice in healthy persons.

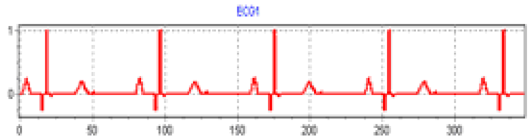

Fig. 10. ECG, lead I.

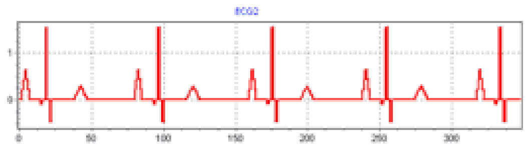

Fig. 11. ECG, lead II

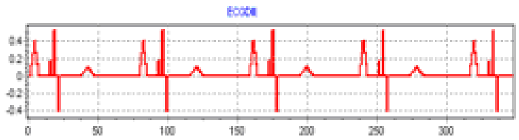

Fig. 12.ECG, lead III.

Thus, using 3D VMPN software application the linear ECG representation of I, II and III leads (80 heartbeats/min) is performed. The case of a healthy heart sinus rhythm is realized.

In the future, we intend to model the obtaining of ECG leads 4 to 12 (in the frontal and transverse planes). Can also be modeled pathological states of the heart: heart attack, arrhythmia, etc.

V. CONCLUSION

It concerns to new technologies which could help to create more flexible and effective applications. Therefore even if the application allows to create real world models there a lot of improvements and new features which must be added at the close future to make such applications more comfortable for work with the models and faster for the simulation.

At the present time with the help of the 3D VMPN application a patient-specific model has been created [3]. This model allows to simulate compensatory mechanisms in type I diabetes. As a part of this model - the model of ECG representation is elaborated. In the future, this model will be developed by modeling ECG representations for 4-12 leads. Thus, will be elucidated the pathological mechanisms involved in cardiovascular diseases: heart attack, arrhythmia, etc.

REFERENCES

[1] Gh. Paun., "Membrane Computing. An Introduction,"– Natural computing Series. ed. G. Rozenberg, Th. Back, A.E. EibenJ.N. Kok, H.P. Spaink, Leiden Center for Natural Computing, Springer – Verlag Berlin Heidelberg New York, 2002, p. 420.

[2] J. L. Peterson, Petri Nets, Theory and the Modeling of Systems, 1981.

[3] A. Profir, R. Damaschin, C. Opinca, L. Prepeliţă, Prepeliţă A., Yang B. Patient-specific computer modelling using 2D and 3D visual membrane Petri Nets. ISSN 1857-2073. Studia Universitatis. Seria "Ştiinţe exacte şi economice", Chişinău, USM, N 2 (42), 2011, p. 57-64.

[4] M. MacDonald, "Windows Presentation Foundation for professionals" – Wilson, 2008

[5] C. Nagel, B. Evjen, J. Glynn, "Professional C# 4.0 and .NET 4.0" - Wrox, 2010

[6] Prof. Macfarlane and Dr. Coleman, Resting 12-Lead ECG Electrode Placement and Associated Problems, SCST Update, 1995.

[7] C. Bunu, Sistemul Cardiovascular. Cursul 4. Electrocardiografia, http://fiziologie.umft.ro/ro/CV4.PDF