A Radial Basis Neural Network Based Agent Module Exploiting ECG Signals to Prevent Heart Diseases

Salvatore Calcagno and Fabio La Foresta
DICEAM, University Mediterranea
89122 Reggio Calabria, Italy
Email: calcagno@unirc.it
fabio.laforesta@unirc.it

***Abstract*—Today, Electro-Cardiogram (ECG) is considered the most important diagnostic tool in cardiology, because its extremely accuracy to reveal potential pathologic heart activities. In the context of a multi-agent system, where agents provide to monitor the health of patients in a personalized manner on the bases of different embedded modules, we propose a module developed with the aim to prevent possible hearth diseases. It is based on a Radial Basis Neural Network (RBNN) able to analyze the ECG signals and to evaluate the impact of some specific parameters for preventing heart diseases.**

***Index Terms*—ECG, Soft Computing, Multi-agent System, Radial Basis Neural Network, Cardiac Diseases.**

I. INTRODUCTION

Nowadays, progresses in computer science, communication and sensor technologies, as well as in the medical researches, have made possible to monitor many aspects of human health. In this context, a prominent role is played by the agent technology [1] which has been applied with success in this field (see for example [8]–[14]). In such a scenario, we are studying to realize a multi-agent system where each personal software agent is associated with a patient and collaborates with a central agency devoted to support the first aid activities suggesting to the health care operators how to use at the best the human and technical resources. More in detail, we are supposing to realize the software agent components with a modular approach so that the agent, on the basis of the different modules that it embeds, can monitor different pathologies (e.g., cardiac troubles, diabetes and so on). Specifically, in this paper, we present a software prototype of the module monitoring the cardiac activity that should be embedded into a personal software agent. In particular, this module exploits the past studies on the Electrocardiogram (ECG). ECG, discovered by Waller and Einthoven in 1903, and consisting of a not invasive reproduction of the heart electrical activity in relation with the body surface potentials, is the most exploited instrument in heart diagnostics especially to investigate fibrillation, ischemia, arrhythmia and many other heart diseases. During the heart ventricular contractions, due to the imbalance in sodium and potassium concentration, the heart muscle behaves like an electric dipole so that it can be described by a vector changing its orientation and amplitude when the depolarization/depolarization activities take place [15]–[18]. Therefore, during the heart activities, some abnormalities may occur distorting the signal so that many algorithms have been developed in order to analyze and interpret the ECG [19]–[22]. The scientific community is heavily involved in research on two different aspects: the first one deals with morphological aspects that affect the cardiac cycle while the second one deals with the timing of events and variations in patters over many beats. Obviously, to investigate and interpret cardiac pathophysiology, we need of models easily implementable [23]–[25] because it is impossible to distort the cardiac activity for studying the effect on ECGs[2]. Moreover, these models help us to mathematically characterize cardiac activity by simulating possibly potentially fatal cardiac diseases. Taking into account the above considerations, the proposed Agent Module was based on a parametric dynamic model for simulating ECG signals relative to single-channel ECGs. Furthermore, with the aim to obtain a flexible model able to give trustworthy results a Computational Intelligence approach has been adopted. As a matter of fact, during the last decades Computational Intelligence (Artificial Neural Networks, Fuzzy Logic, Support Vector Regression Machines, genetic algorithms, particle swarm techniques) have been employed with success to solve a wide variety of problems ranging from microwave engineering [26], [27], [28], non destructive testing evaluation (NDT) [29], [30], transportation engineering [31], to biomedical engineering [32]. Among the various methodologies available in this field, in the present work, an approach based on the exploitation of a Radial Basis Neural Network (RBNN), is proposed. The main reason of this choice is due to the the ability of the RBNN to handle pattern estimation problems [32]–[35]. More in detail, by means of a RBNN, very useful for pattern estimation problems [26], [32]–[34], a parameterized model for evaluating the impact on the ECG trends is built. Starting from the evaluation of

[1]The interested reader might refer to an overwhelming number of surveys on the matter among which [1]–[7].

[2]Even though the problem could be avoid by studying the ECG database.

TABLE I: Empirical Parameters

	P	Q	R	S	T
time (sec)	-0.25	-0.025	0	0.025	0.25
ϕ_j (rad)	$-\pi/3$	$-\pi/12$	0	$\pi/12$	$\pi/3$
h_j	1.25	-5	30	-8	1
k_j	0.25	0.1	0.1	0.1	0.5

the RBNN performances by means of the variation of its spread factor related to each feature carried out by the signal, the spread factor taking into account the trade-off between performances and neural net complexity is chosen. At the end, a suitable neural net based on radial basic function is trained testing the performances of the model. Finally, the trained RBNN represents the module exploited by each agent to monitor the cardiac activity of its associated patient. The paper is organized as follows: Section II gives the basics on the proposed model for reproducing the ECG signal. Section III presents the experimental dataset used to build our RBNN model. Section IV describes the RBNN based Agent module. Section V describes the proposed multi agent architecture for health care. Finally, conclusions are given in section VI.

II. The Proposed ECG Model

ECG is the graphic reproduction of the electrical activity of the heart during its operation, recorded on the surface of the body.

Pulses in the myocardium generate potential differences time and space-varying that can be recorded by electrodes on the surface of the human body. ECG, with a characteristic trend only varied in the presence of problems, is characterized by several positive and negative traits called "waves" which repeat at each heart cycle (Figure 1). P-wave, small in size, corresponds to the atrial depolarization. The QRS complex, a set of three consecutive waves, corresponds to ventricular depolarization. T-wave represents the ventricular re-polarization [5].

Globally, the distortion of PQRST complex denotes heart diseases so that the analysis of ECG reveals the presence of major cardiac pathologies.

As showed in [5], ECG signal can be carried out by solving a system of three coupled ordinary differential equations. Formally, an ECG signal $f(t)$, indicating the module 2π operation and the empirical parameters by means of $|\ |_{2\pi}$ and (h_j, k_j, ϕ_j) respectively (Table I), can be reproduced as follows:

$$\dot{f}(t) = \sum_{j \in \{P,Q,R,S,T\}} h_j |\phi - \phi_j|_{2\pi} e^{-\frac{\Delta\phi_j^2}{2k_j^2}} - f(t) \qquad (1)$$

where ϕ is an angular dynamic parameter which determines the ECG deflection. In order to evaluate ϕ, in [5] (1) was coupled with the dynamic system:

$$\begin{cases} \dot{H} = \xi H - \omega\sigma \\ \dot{\sigma} = \xi H + \omega\sigma \end{cases} \qquad (2)$$

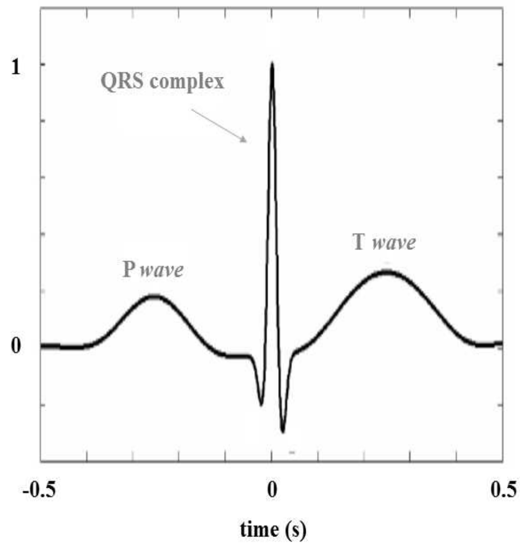

Fig. 1: Trend of an ECG in a healthy patient.

in which ω is a parameter related to the heart rate while $\xi = 1 - (H^2 + \sigma^2)^{1/2}$ obtaining $\phi = tan^{-1}\{2(\sigma H)\}$. From a geometric point of view, fixing the angular velocity ω, ϕ can be computed by moving amount the $H - \sigma$ limit line.

In addition, to simulate cardiac diseases, it is sufficient in (1) to set differently the parameters (h_j, k_j, ϕ_j) at the expense of the model flexibility. In such a context, the proposed approach parametrizes the $H - \sigma$ limit line modifying (2) adapting the model to the PQRST complex for a timely control generalizing the limit path elliptically by both rotation and linear transformation as follows:

$$\begin{pmatrix} \bar{H} \\ \bar{\sigma} \end{pmatrix} = \begin{pmatrix} cos\Phi & sin\Phi \\ -sin\Phi & cos\Phi \end{pmatrix} \begin{pmatrix} a & 0 \\ 0 & b \end{pmatrix} \begin{pmatrix} H \\ \sigma \end{pmatrix} \qquad (3)$$

which allows to compute ϕ as $tan^{-1}\{2(\bar{\sigma}\bar{H})\}$. It is worth watching that (2) and (3) are equivalent if $a = b = 1$ and $\Phi = 0$. The advantage of the proposed procedure liens in the fact that, maintaining the same computational complexity, it is possible to characterize the distortion of the complex by means of (a, b, Φ).

As an example of ECG alteration we show in Figure (2) some modification of ECG by setting different values of parameters according to the proposed model.

III. The Experimental Dataset

With the goal of creating a neural learning model, it is imperative to create a training database. So, by using the model developed and proposed in the previous Section, we have built an artificial database of almost 800 ECG signals. In particular, if f is the sampling frequency, we fixed the time step $f^{-1} = \Delta t$ so that we could apply a 4- Runge-Kutta procedure [36], [37] to obtain a good number of ECG signals whose peculiar characteristics, according to [23], [38], [39], are listed in Table II. In addition, the time intervals have been computed between two consecutive beats (the so-called

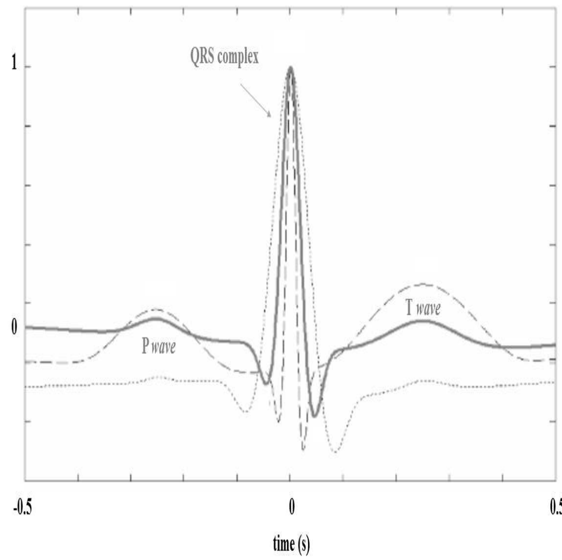

Fig. 2: An example of ECG signal carried out by the proposed model. The continuous line is referred to a normal ECG; the other lines are related to two pathologies whose parameters are $(1,\ 0.7,\ \pi/4)$ and $(1,\ \pi/6, 0.1)$ respectively.

RR-interval); the amplitude of RS-intervals was considered in terms of Volts. Finally, we have also considered the QT-intervals.

In order to test the performance of the proposed model, another database formed by 200 ECG signals has been carried out by means the same procedure as above specified.

Finally, it is worth to emphasize that the training system consists of three inputs, (a, b, Φ), and three outputs, (RR-intervals, RS-amplitude, QT-intervals). The choice of considering the RR-intervals as an output of the procedure is motivated by the fact that they provide peculiar information on the physiological state of the patient characterizing both bradycardia and tachycardia. Since the ratio of the power in both the low and high frequencies components can be considered for the sympathovagal balance [10]. In this paper, this ratio is defined as [0.015, 0.15]/[0.15, 0.4].

Regarding the choice of considering the RS-amplitudes as input, it is motivated because it measures the voltage gap of the second section of QRS-complex which causes the ventricles depolarization. In addition, RR-intervals and RS-amplitude are strongly correlated: if RR-interval increases, then the path has more time to be pushed into the sequence R and S waves.

Finally, QT-intervals cannot be missing among the inputs because they represent the time-gaps between the ventricular depolarizations and the end of ventricular repolarizations: if QT-intervals are too large the death of the patient is incoming.

IV. The RBNN based Agent Module to prevent heart diseases.

In the Computational Intelligence context, the Artificial Neural Networks (NNs) are consolidated systems that, by mens of learning procedures, are able to create the nonlinear and multi-variable inputs-outputs mapping [29], [31].

TABLE II: Values assigned to parameters for the construction of the artificial ECG signals database.

Parameter	Amplitude
ECG f	256
Internal sampling frequency	512
Mean heart rate	70
Number of beats	256
Low frequency/High frequency (LF/HF) ratio	0.6
Std of heart rate	1.2 beat/minute
a (no inconsistent ECG)	≥ 0.52
b (no inconsistent ECG)	≤ 1
rotation	$-\pi/2 \leq \Phi \leq \pi/2$

Specifically, RBNNs, considered as excellent functions approximators, are usually constituted by means of three layers of nodes. As shown in Fig. 3, starting from left side (inputs layer) to right one (outputs layer), just one hidden layer, where radial basic functions are exploited, takes place. The parameters showed in Fig. 3 are detailed in Table III.

In addition, as displayed in Fig. 3, the input vector **p** and the matrix $\mathbf{IW}_{1,1}$ are exploited respectively as input and weight matrix for $||dist||$ box producing a vector, with cardinality is N^1, whose elements are the distances computed between **p** and the rows of $\mathbf{IW}_{1,1}$.

The input for the radial basic function is the vector distance computed as before mentioned multiplied by the bias (element allowing the sensitivity of the radbas neuron to be tuned). It is worth to observe that the radial basic function (in our case, e^{-n^2}), for input equal to zero, is the maximum value equal to unity and, in addition, if the output decreases, $||dist||$ decreases: in this way a radbas neuron works as a detector producing unity if **p** is equal to its weight vector.

In this work, if we consider the Spread Factor SF, which represents a sort of measurement of the function smoothing, the performance of RBFNN depends on the variation of SF so that the larger is SF, the smoother is the function approximation. However, SF, since it is too large, could generate numerical problems so that it is necessary to guarantee the overlapping among active input regions of the radbas neurons ensuring that a lot of radbas neurons have large outputs at any instant.

This procedure is able to simultaneously guarantee both a function smoother and a good generalization of the network. About the setting of the weight for the first layer, see Table IV. Regarding the second-layer, indicating by $\mathbf{LW}_{2,1}$ and $\mathbf{b}_2$ the second-layer weights and the bias respectively, $\mathbf{LW}_{2,1}$ is achieved by solving the following linear formulation

$$\boldsymbol{T} = \left(\boldsymbol{LW_{2,1}b_2}\right)\begin{pmatrix}\boldsymbol{A_1}\\ \boldsymbol{I}\end{pmatrix} \tag{4}$$

where $\mathbf{A}_1$, $\mathbf{I}$ and $\mathbf{T}$ indicate the output of the first-layer, the identity matrix and the output matrix respectively.

In order to evaluate the performance of the proposed RBNN model, a set of standard statistic indexes have been taken

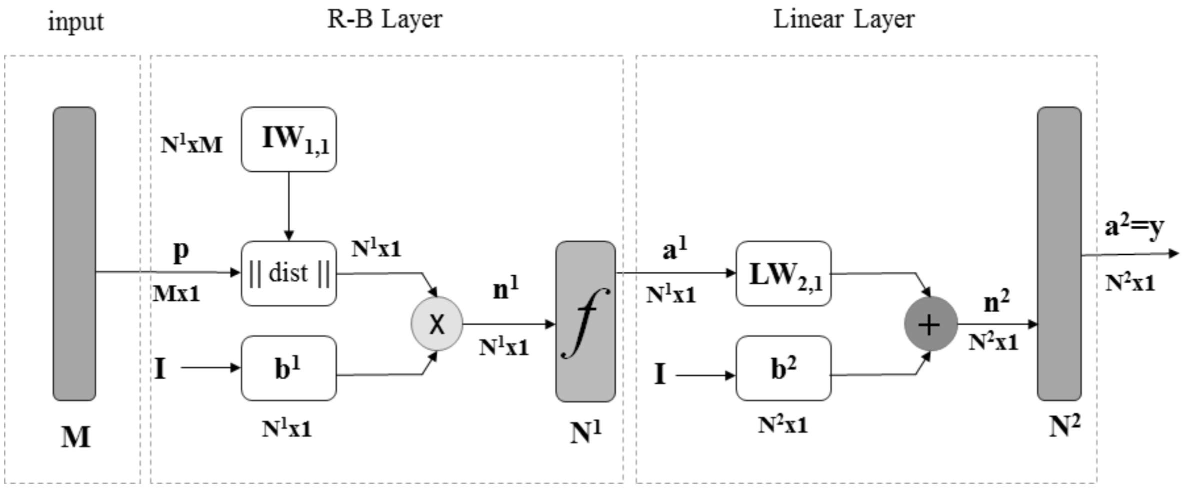

Fig. 3: Simplified representation of the RBNN.

into account. In particular, as showed in (5), Root mean Squared Error (RMSE), Root Relative Squared Error (RRSE), Mean Absolute Error (MAE), Relative Absolute Error (RAE) and Willmott's Index of Agreement (WIA) [40] have been considered to evaluate the performance by varying the spread from 0.25 to 20 with a a step equal to 0.25.

$$\begin{cases} RMSE = \left(\frac{1}{m}\sum_{j=1}^{m}(y_j-\bar{y}_j)^2\right)^{\frac{1}{2}}; \\ RRSE = \left(\frac{\sum_{j=1}^{m}(\bar{y}_j-y_j)^2}{\sum_{j=1}^{m}(y_j-\bar{y})^2}\right)^{\frac{1}{2}}; \\ MAE = \frac{\sum_{j=1}^{m}|\bar{y}_j-y_j|}{m}; \\ RAE = \frac{\sum_{j=1}^{m}|\bar{y}_j-y_j|}{\sum_{j=1}^{m}|y_j-\bar{y}|}; \\ WIA = 1-\frac{\sum_{j=1}^{m}(y_j-\bar{y}_j)^2}{\sum_{j=1}^{m}(|y_j-\bar{y}|+|\bar{y}_j-\bar{y}|)^2}; \\ \bar{y}\text{=predicted feature} \\ m\text{=cardinality of the testing patters.} \end{cases} \tag{5}$$

The proposed procedure has been implemented on Intel Core 2 CPU 1.47 GHz using MatLab R2013a selecting an SF value equal to 0.77 carried out by means a trade-off between the complexity of the net and the same performances; for this computation, the time elapsed was almost equal to 50 minutes.

The training procedure has been carried out for a 29-hidden-neurons RBNN whose time elapsed was equal to 0.96 seconds. The obtained results have been collected in Fig. 4, where RMSE, for each feature, is displayed vs the SF variation and in Table V where the comparison among the values of the statistical parameters is evident putting out a good quality of the tuning achieved by means of the proposed RBNN procedure.

V. The Health Care Multiagent Architecture

The multi-agent system that we are designing consists of a central Agency and a set of personal software agents, each one associated with a user (i.e., patient) to monitor. In particular, each personal agent can be configured with specific modules on the basis of the pathologies affecting its associated user. Moreover, each personal agent is thought to be a light software component able to run on a personal devices, in order to monitor its user throughout his/her daily activities. Nowadays, it is possible because mobile devices have suitable computational, storage and communication capabilities to host and support such personal agents in all their tasks. At the same time, more and more powerful sensors, provided of wireless communication capabilities, are currently available. More in detail, the agent gathers the data coming via wireless from the sensors both directly applied on the associated user (e.g.,

TABLE III: Parameters of the RBNN model.

Parameter	**Specification**
M	cardinality of the input vector
N^1	cardinality of the set of neurons related to layer 1
N^2	cardinality of the set of neurons related to layer 2
Radial Basic Function (radbas)	activation function of N^1
Linear Function (purelin)	activation function of N^2

TABLE IV: Setting of weights and biases

	Specification
first-layer weights	transpose of input matrix
first-layer biases	cardinality of the set of neurons related to layer 1
radial basic function	cross 0.5 at weighted inputs of $\pm SF$

TABLE V: Performance of the RBNN exploiting statistical evaluators

Inputs	**RMSE**	**RRSE**	**MAE**	**RAE**	**WIA**
RR-intervals	0.002	0.37	0.004	0.31	0.94
RS-amplitudes	0.03	0.239	0.031	0.196	0.891
QT-intervals	0.006	0.324	0.005	0.387	0.922

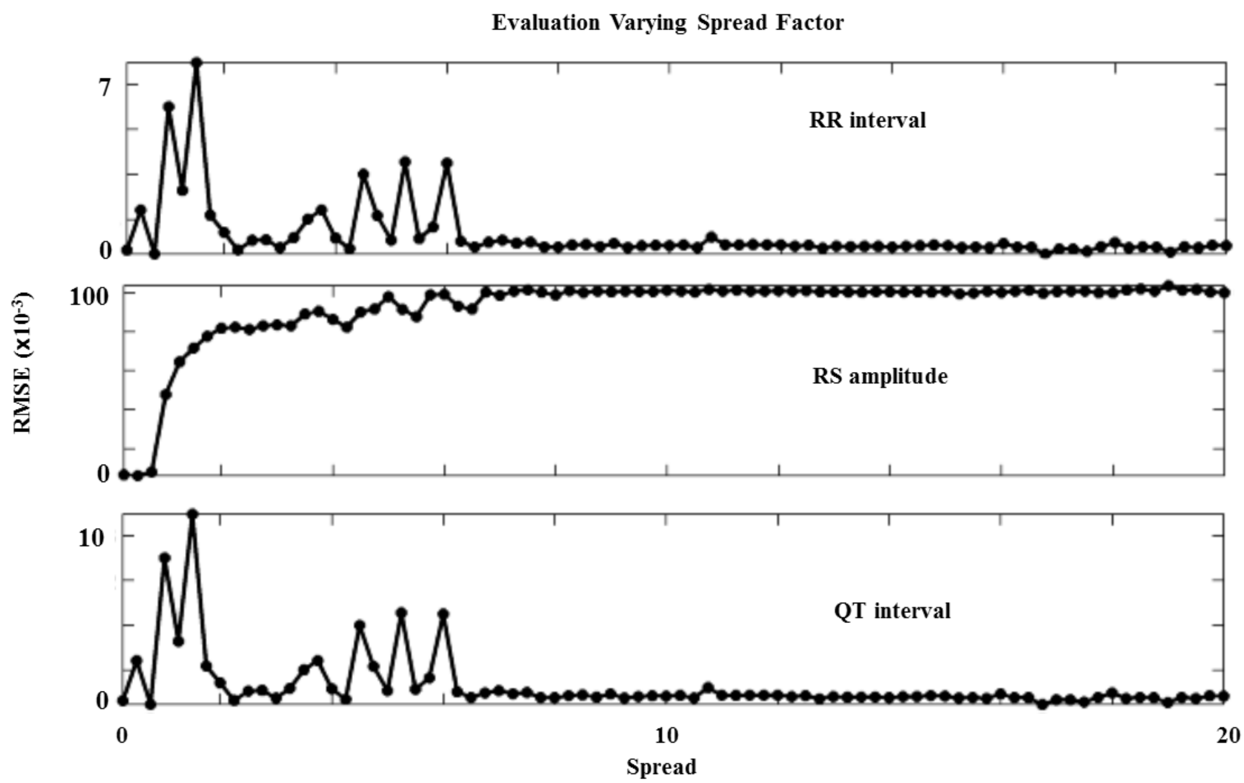

Fig. 4: Performance of the model in terms of RMSE for each input vs the spread.

ECG or glycemia sensors) and into his/her environment where he/she lives (e.g., movement sensors). These data acquired by the agent are analyzed by the corresponding agent module in order to evaluate the health state of the monitored user. When the agent detects a potential health risk then it provides to inform its Agency. The aim of the Agency is that of supporting the assigned operators in managing the first aid activities by suggesting the activities to carry out and the best use of the available human and technical resources (i.e., medical doctors, health-care assistants, ambulances and so on).

A. *Preventing Heart Disease*

In the aforementioned multi-agent scenario, we describe the case of a patient affected by heart troubles that is monitored by a personal software agent running on his/her mobile device (e.g., a smartphone), equipped with a heart module embedding the trained RBFANN previously described. The agent provides to analyze the data coming from the patient's ECG sensors and required in input by the RBFANN. If the agent detects the symptoms of a potential health diseases then it provides to alert both its patient and its remote Agency by exploiting the device communication capabilities.

When the Agency receives the agent alert then it, on the basis of both the potential heart risk and the health resources available at that time, provides a list of suggestions to the designated operators in order to help at the best the unfortunate user.

VI. Conclusions

In this paper we have presented a study to realize a module for monitoring patients with heart troubles, as a part of a software agent equipment in the context of a more complex and ambitious multi-agent system oriented to monitor the patients' health.

To realize this module, in order both to solve complex regression problems and develop an alert system, a RBNN architecture has been exploited. In such a context, starting from both a biomedical problem where the estimation of features for ECGs recording is required and a self-modified dynamic model, the RBNN performances have been estimated to put out pathological ECGs when heart diseases appear. The proposed agent module has provided reliable results to evaluate the parameters of McSharry's modified model carrying out pathological events in ECG.

As future works, we are considering the advantages of including in the design of the proposed system (*i*) a control on the reliability of the sensor data in order to avoid the risks due to wrong or missed alarms and, to this purpose, trust and reputation system appear as potential candidates for realizing it also on the basis of recent models and applications [41]–[43] and (*ii*) an evolutionary strategy [44], [45] for improving in time the Agency performance.

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