Artificial neural networks for acquisition and processing of sensors data in a radiotherapy application

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Abstract: This paper presents a practical part of work that we have begun to realise for several months and it is planned for several steps. In this paper, a part devoted to acquisition and processing of coded data from temperature sensor of type MS6503 used in radiotherapy rooms of the Hospital Pierre and Marie Curie Centre (PMCC) is presented. The aim is to acquire and check remotely the temperatures of rooms to trigger alarms and their control thereafter in order to avoid mistakes of manipulation which are deadly for patients if they happen or arise. For this, a system modelling is made before proceeding to the implementation in practice. During the implementation, several problems have occurred such as the legibility of the received data that has been encrypted. To overcome this problem, an artificial neural network type of multi-layer perceptron (MLP) is used to acquire and decrypt the temperature data received from the sensors placed in the treatment rooms. The obtained results show that the neural network used has decrypted well the received data. It is the reason for which this technique has been implemented in the realised solution.

Keywords: data acquisition and processing; temperature sensor; radiotherapy rooms control; artificial neural network; modelling.


Biographical notes: Kheireddine Lamamra received his Engineering degree in Electronics Specialty of System Control in 1999 from the University of Guelma, Algeria. He received his Magister degree in the same specialty in 2001 and in 2012 he received his PhD from the University of Mentouri of Constantine (Algeria). In 2015, he received his Habilitation (Qualified for Professorship) degree from the University of Batna (Algeria). He worked during 1999–2003 at the Computer Science Department of the University of Mentouri of Constantine, and Assistant Professor at the Department of Electronics at the University of A. Mira of Bejaia during 2003–2008. Currently, he is a member of the Laboratory of Renewable Energy Mastering at the University of A. Mira of Bejaia (Algeria) since 2008 at Electrical Engineering Department of the University of Larbi Ben Mhidi of Oum El Bouaghi (Algeria). He is an Associate Professor and Researcher.
1 Introduction

In radiotherapy services, treatment of patients requires constant vigilance and following with great attention. It is very important to be sure that the conditions in which the patient is exposed are well in order to avoid any risk. This concerns several individuals who have relationship with it (physicians, technicians, physicists and manipulators) who must take care and treat patients with great attention since they use dangerous devices like linear accelerators (López, 2012; Ortiz et al., 2009). It is hard to control all these people and checking every day the state and quality of equipment (Fraass, 2008), for example, the medical, physicist and technical staff of the radiotherapy service of Hospital Pierre and Marie Curie Centre (PMCC) of Algiers is composed of fifty people. This paper presents a part of a system that we have realised to help avoid errors of manipulation and management. It improves the quality of services and increases the medical care while applying some medical, technical and physical procedures.

The work described permits the application of these procedures so that the personnel of the radiotherapy service are able apply it. The main purpose is to avoid mistakes of manipulation and ensure a better monitoring and better management thereby eliminating dangerous errors. These errors are usually deadly for patients if they happen or arise. Such errors and accidents can occur in any radiotherapy department even in developed countries (Allam, et al., 2013b; Holmberg, 2007; Eichholz, 2004).

Currently, the problem of the quality in services and the accidents in radiotherapy services in the world are not well solved (Abdel-Wahab et al., 2011; Boadu et al., 2009; MÉDICA, 1991). The first version of this system is already implemented and functional in the radiotherapy service of the Hospital PMCC in Algiers (Allam, et al., 2013a). In this paper, we present the acquisition and the processing of temperature data delivered by temperature sensors used in radiotherapy rooms of the hospital and the way to treat and decrypt it by artificial neural networks of type multi-layer perceptron (MLP).

The temperature sensor used in the PMCC radiotherapy rooms is type of MS6503. In order to display the temperature values through a specific application that we implemented practically in the aim to control these rooms, this has caused us a major problem because the received data from the sensor are encrypted and illegible so that its direct use not possible, which required us to seek an approach to decrypt these data in order to have the exact temperature values of the radiotherapy rooms. For this we have used artificial neural networks trained by the back-propagation algorithm to acquire and decrypt the data received from sensors (Yin et al., 2013). The choice of neural networks is made because among the advantages of a neural network is its ability to adapt to the conditions imposed by any environment, and the ease of changing its parameters (weight, number of neurons, etc...) depending on the behaviour of its environment (Wang et al., 2015a; Tremori et al., 2016; Lamamra et al., 2015; Xie et al., 2014; Tselios et al., 2013; Lamamra et al., 2011). This work is carried out after a modelling phase. Modelling aims to represent a real process in the form of representative model by mathematical functions. In the case where these functions are unknown, the process is considered as a black box. In this case the modelling is done by some tools such as artificial neural network used in this work. The model must accurately simulate the behaviour of real-modelled process and allows to better understand the real process and control its complexity (Lamamra et al., 2015; Tselios et al., 2013). In this work the data decryption block is modelled by neural networks before its implementation in the monitoring and control platform.

This paper is organised as follows: in the second section it presents the computer and wired sensors network constituting the PMCC radiotherapy service, in the third section, the setup of the wired sensors network is presented, and in the fourth section describes the modelling phase and how data are acquired and decrypted using an artificial neural network, and finally in the fifth section, the results of the developed approach are presented.
2 The computer network and the wired sensors

The computer system consists of five personal computers, one server computer, three linear accelerators (Varian model), two scanner simulators (Varian and General Electric), and five temperature and humidity sensors of the radiotherapy treatment rooms (Allam et al., 2013a). Computers are placed in a network and three of them are used to control the check list of the apparatus (linear accelerators). These three computers are put outside the treatment rooms. The server computer is used as a data server in order to store all data of the system (the check list of the devices, the temperature and the humidity data, physicians and patients’ management). Four personal computers are devoted to the manipulators (physicians, physicists and technicians) to collect medical information about patients during sessions of the simulation and radiation treatment and their contact details and any other necessary information. The service head or the technical manager of the radiotherapy services controls and supervises all room machines on only one computer screen, through one computer used to view all the screens of the four computers linked to the four treatment rooms in one big screen working in real time (active multiple windows). One computer is linked to the two simulation room. In treatment rooms, five temperature and humidity sensors are used with a serial RS232 port. This port is applied inside the four treatment and simulation rooms with the three linear accelerators and the two scanner simulators. The sensors with the computers and the other machines form a network system similar to a multi-agent system; they consist of a set of agents, located in a certain environment and interacting according to specific relationships. In this system an agent can be represented by the sensors, computers and the other used tools (Bruzzone et al., 2016; Medini, 2015; Šperka et al., 2015). This system is used in order to improve the quality of services and to increase the medical care. In fact, through this system and using simple medical, technical and physical procedures and also checking application, we can avoid handling errors that could kill or disable patients.

3 Setup of the wired sensors network

A primary version of the realised control application of the treatment rooms temperature is already implemented and one of the application interfaces is presented in Figure 1. In this application version we designed the verification and control of some physical and medical procedures and the implementation of all temperature and humidity sensors of the treatment rooms. The scientific and technical cooperation with the medical staff of the Hospital PMCC’s radiotherapy service (physicians and physicists), the technicians of research centre of ‘Advanced Technology Development Center of Algiers’ and with contribution of researchers from the University of Oum el Bouaghi of Algeria has led to this solution. The real time control of the treatment rooms and the simulation room in one screen (multiple screen solution) achieved by using the LabVIEW software is shown in Figure 1. LabVIEW is a graphical programming platform suitable for systems of all sizes, from the design phase until the test phase. Its ability to integrate with existing software and old generation equipment is very good, while taking full advantage of the latest computer technology. LabVIEW provides the tools to solve several current problems, and offers the ability to innovate faster and more efficiently (Chen et al., 2014; Tao et al., 2013; Travis et al., 2006).

Figure 1 Interface of a real time control of one treatment room (see online version for colours)
Users of the platform in radiotherapy services of PMCC often use the French language. This is the reason that everything that appears on the platform interface is in French. The English translation of the content of the interface of the platform according to the numbers shown in the figure is as follows:

1. header of the platform:
   - PMCC
   - control platform of the radiotherapy department
   - treatment room N° 1
   - linear accelerator 2100C
2. temperature; humidity; inverter
3. date and time
4. stopwatch
5. stop button of the stopwatch
6. temperature and humidity values of the inverter in real time
7. temperature and humidity values of the room in real time
8. real-time status indicators:
   - stat of the linear accelerator 2100C
   - anomalies in the linear accelerator 2100C
   - stat of the ozone room
   - stat of the inverter
   - checklist machine
   - water pressure
9. councils of the department head
10. treatment report
11. patient number.

Radiotherapy treatment procedure using radiation has a central role in modern healthcare. To ensure maximal benefits and minimal risks, it is essential that these techniques rely on adequate dosimetry and medical physics procedures. The dosimetry refers to the accurate measurement of radiation doses and it is essential to enable patients to have a proper medical treatment. In therapeutic procedures, accurate dose measurement is critical for effectively treating patients. The ARIA (trademark of Varian Medical System) oncology information system of Varian (registered trademark) which links the linear accelerators (Varian models), the scanners, the simulators and the computer’s network medical control procedures is used in the radiotherapy service of the Hospital PMCC.

This system does not guarantee to eliminate mistakes of manipulations and human fatal errors for the patients’ treatment. The control platform that we have realised runs in parallel with this system, but it is not physically linked with it in order to control and to ensure that all procedures (physical, medical and technical) are executed without errors by the staff of the medical oncology department. This control platform is complementary to the ARIA oncology information system (Allam et al., 2013a, 2013b).

4 Modelling and data decryption using artificial neural networks

The sensor used in the PMCC Hospital radiotherapy treatment rooms is of type MS6503, it is a temperature and humidity sensor and the temperature displayed through the liquid-crystal display (LCD) screen of the sensor presents a problem because it has a non-transparent communication protocol because the sensor is provided with a specific software that lets it read the temperature and humidity, but if the user needs to integrate the sensor into another application like monitoring a treatment room, he cannot read the data sent by the sensor via the RS232 serial port because its protocol and data format provided by the latter are unreadable and unknown, and the data received through this port are encrypted.

To solve this problem and help to acquire the real values of the temperature of the treatment room, we have opted to model the data decryption block before its implementation in the control platform using an MLP neural network trained by back-propagation algorithm to decrypt data. It is an often used method of training artificial neural networks used usually with an optimisation method like gradient descent. It is a method which calculates the error gradient for each neuron of an artificial neural network from the last layer to the first. It is often the error correction algorithm based on gradient calculation using the back-propagation. It requires a knowledge of the desired output for each input value to calculate the cost function gradient (Bhuvana et al., 2015; Wang et al., 2015b; Subramaniam et al., 2007; Shieh et al., 2007). The diagram of acquisition and data decryption is shown in Figure 2.

The neural network used to decrypt the acquired data from the sensor is used in two stages. The first stage is the training phase: in this phase the neural network is adjusted and formed according to its error. In this phase we have trained the neural network on a set of data using encrypted codes of the sensor as inputs of the neural network and the target are the temperatures corresponding to these codes. These temperatures are noted directly and manually from the sensor placed in a radiotherapy treatment room, these values have been read directly through the LCD screen that provides the MS6503 sensor (Figure 3), this work is very delicate and tiring and we have taken a very large time to make it.
During the modelling of the data decryption block of the sensor, the weights of the neural network are at first initialised with random values and then a set of data of the temperature sensors is used to learn this network and for each code a target value is corresponding. The output function of the neural model used is a sigmoid given by the formula (1):

\[ y_j = \frac{1}{1 + e^{-\alpha j}} \]  

(1)

The adaptation of the weight between the neuron \( i \) and the neuron \( j \) is done as follows:

\[ \Delta w(i, j) = \alpha \delta_j y_i \]  

(2)

where

- \( \alpha \) is a coefficient between 0 and 1.
- \( \delta_j \) is the characteristic error of the neuron \( j \) at the input value \( y_i \) and is calculated by the formula (3):

\[ \delta_j = (u_j - y_j) y_j (1 - y_j) \]  

(3)

The calculation of the error to the hidden neurons is then recursively done by the descent of the gradient as follows:

\[ \delta_j = y_j (1 - y_j) \sum_{k=1}^{Nn} \delta_k w(j, k) \]  

(4)

where \( Nn \) is the number of neurons.

The application of this technique on the neural network for a set of data, will allow it to tend to minimise the error and thus model as close as possible to the neural model that represents the desired function between inputs and outputs. At the end of this modelling phase, the criterion of the error of the neural model must be as small as possible. In our case the criterion of modelling error \( (e_{\text{m}}) \) is the quadratic error between the data value \( (v_{\text{m}}) \) at the output of the neural model and the target data value \( (v_t) \), this criterion is given by:

\[ e_{\text{m}} = (v_{\text{m}} - v_t)^2 \]  

(5)

where

- \( v_{\text{m}} \) is the data value of the neural model output
- \( v_t \) is the target data value.

The second phase is the validation phase, in which a further set of encrypted data of the sensor are used at the input of the artificial neural network (encrypted codes that were not used in the first phase) and the target is the real values of the temperature also manually noted from the sensor screen.

In this phase we would like to verify the quality of the neural network to decode the sensor’s data because at this stage we do not act on the training of the neural network, and we use the same network after its training and constructing in the first phase.

At this stage, the artificial neural network could be used directly to determine the temperatures corresponding to the encrypted codes received from the sensor through the RS232 port of the computer of control room.
5 Results and discussions

After building and training the decryption neural network of data codes, received from the sensor of the radiotherapy treatment room, the neural network is then implemented and connected to the temperature control application of the radiotherapy treatment room that we designed in practice.

To check the reliability and efficiency of the neural network to decrypt the codes for the temperatures remotely recorded; we have chosen a wide range of temperature values by applying to the sensor, temperatures ranging from 0°C to 35°C. We note that according to some experts in radiotherapy, temperature in radiotherapy room should not drop below 20°C and should not exceed 25°C.

The number of recorded temperature data and the decoded data is 300; these data have been sorted in ascending order. The neural network structure is as follows.

The output layer is composed of a single neuron and it corresponds to the temperature values decrypted by the neural network \( T_{nn} \).

The input layer is composed of two neurons; the inputs of the network are encrypted codes from the sensor \( C_s \) and the instantaneous error \( e_i \) which is the difference between the real temperatures \( T_r \) recorded manually from the sensor’s LCD screen and the temperature values decrypted by the neural network \( T_{nn} \), then the instantaneous error is given by the following formula (6):

\[
e_i = (T_r - T_{nn})
\] (6)

The network consists of a single hidden layer, the number of neurons in this layer is chosen by trial and error, each time we choose a number of neurons we check the value of the global squared error, and after several tests we choose the neural network structure that gives us the lowest possible error.

The results presented below correspond to neuronal structure with sixteen neurons in the hidden layer. In the figures, we only present the validation results of the neural network as training results are almost identical.

Figure 4 shows the real temperatures measured directly from the sensor \( T_r \) and decrypted temperatures remotely by neural network \( T_{nn} \).

Figure 5 is a zoom-in of Figure 4, in order to show a portion of the difference between the real and the decrypted temperatures.

Figure 6 represents the instantaneous error, and Figure 7 shows the quadratic error.

The global accumulated quadratic error is given by the formula (7) below:

\[
e_{qc} = \sum_{k=1}^{n} e_i(k)^2
\] (7)

where \( n \): number of data.

According to the obtained results this error is equal to \( e_{qc} = 2.5212 \). We note that the maximum instantaneous squared error occurred in the encrypted code number 42 with a temperature error equal to \( e_{max} = 0.0998 \), and the second biggest error appeared in the encrypted code number 228 with a temperature error equal to 0.0759 (Figure 7).

These error values are acceptable. These results show clearly that the neural network was able to decode the encrypted code of the sensor, effectively. We consider these practical results very satisfactory.
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Figure 5  Zoom-in of Figure 4 (see online version for colours)

Real Temperatures measured directly from the sensor (Tr)
and decrypted Temperatures remotely by Neural Network (Tnn)

\[ \text{Real Temperatures measured directly from the sensor (Tr)} \]
\[ \text{and decrypted Temperatures remotely by Neural Network (Tnn)} \]

Temperature data number

Note: Portion of the difference between the real and decrypted temperatures.

Figure 6  The instantaneous error (see online version for colours)

Instantaneous error

Temperature data number

Figure 7  The quadratic error (see online version for colours)

Quadratic error

Temperature data number
6 Conclusions and future directions

The monitoring of the status of patients during caring is always a concern of doctors, nurses and anyone who has a relationship with this operation. In radiotherapy it is essential to keep stable and without error conditions to which the patient is subjected in order to preserve his health and his life. Simple mistakes can lead to death of the patient. For this, the design of systems assisting in the struggle against the medical errors, is necessary and very important. In our work, we have designed a system (a platform with LabVIEW) for the monitoring and control of the manipulations of doctors and radiotherapy service staff to improve the quality of care and ensuring avoid any possible error. In this paper we have presented a part concerning the acquisition and deciphering of coded data received from temperature sensors (type of MS6503) used previously (before designing our system) in radiotherapy treatment rooms of the Hospital PMCC, and the goal is to remotely check the temperature of rooms and if necessary to trigger alarm and control thereafter.

To use directly data received from the sensors through the RS232 port was not possible because the data are encrypted in an unknown way; it is the reason which pushed us to seek an approach to solve this problem. For this we have modelled the data decryption block using an MLP artificial neural network trained by back-propagation algorithm, and then it was implanted in the control platform to decrypt the data.

This work, which lasted several months, shows that an important step in our control project is completed successfully and the obtained results are very satisfactory. The implementation of the system in practice greatly helped the monitoring of patients and facilitated the task of the staff members during treatments.

References


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