Metallic Artifacts Removal in Breast CT Images for Treatment Planning in Radiotherapy by Means of Supervised and Unsupervised Neural Network Algorithms

V. Bevilacqua[1], A. Aulenta[1], E. Carioggia[2], G. Mastronardi[1], F. Menolascina[1,2], G. Simeone[2], A. Paradiso[2], A. Scarpa[1], and D.Taurino[1]

[1] Dipartimento di Elettrotecnica ed Elettronica, Polytechnic of Bari,
Via E. Orabona, 4, 70125, Bari, Italy
[2] I.R.C.C.S. - Istituto Tumori "Giovanni Paolo II"
Via S. Hahnemann, 10, 70126 , Bari, Italy
bevilacqua@poliba.it, giovanni.simeone@oncologico.bari.it

Abstract. In this paper medical applications of supervised and unsupervised neural networks image processing algorithms are presented and discussed by means of quantitative experimental results in the field of radiotherapy. The investigated case study concerns the problems and the consequent solutions referred to the two phases of the treatment plan necessary after the quadrantectomy of a cohort of patients affected by breast cancer.

Keywords: metallic artifacts removal, radiotherapeutic treatment planning, dose-volume histogram, neural networks.

1 Introduction

The adjuvant radio-therapeutic treatment for a patient undergone to a breast quadrantectomy consists of two phases: first, with two-field tangential photon beams on the whole breast (total dose 50 Gy, fraction dose 2 Gy); second, with a direct field of electron beam at the surgical site (total dose 10 Gy, fraction dose 2 Gy). In many radiotherapy centres, during the treatment simulation phase a metallic wire (40% tin and 60% lead, 0,7 mm diameter) is applied to patient skin around breast and along the surgical scar. This wire allows physicians to identify treatment volumes and detect their edges.

However the same wire produces artifacts in its neighbourhood in CAT images acquired by a commercial CAT simulator dedicated to radiotherapy.

During treatment planning, executed by SUNRISE version of a Treatment Planning System called PLATO, these artifacts create the following problems:

- in the plan involving tangent photon fields, dose hot spots form at the entrance of the same fields (corresponding to the wire) and to the under dosed area below.
- in the plan involving a direct electron field, clearly under dosed areas form at the centre of the treatment volume in comparison to the lateral areas.

The use of automatic procedures to remove artifacts allows, in the case of a patient taken into account, to eliminate artifacts' effect almost completely.

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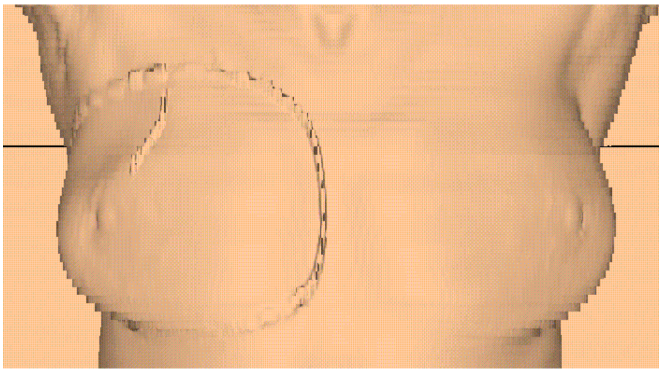

Fig. 1. 3D reconstruction of patient skin with applied wide maps

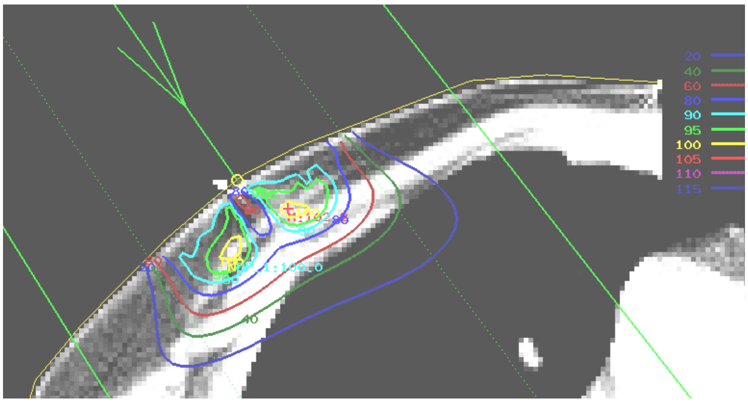

Fig. 2. Iso-dose lines for electrons' field before artifacts' removal maps

This implies a dosimetric evaluation of planes more alike to real treatment, since patient does it without wire.

2 Neural Network

Artificial Neural Networks are inspired by biological nervous systems and are in the past years implemented very often in medical images applications [2][3][4]. It is composed of a large number of highly interconnected processing elements called neurons that work all together to solve specific problems. All connections among neurons are characterised by numeric values called weights that are updated during the training. There are two kinds of training algorithm: supervised learning and unsupervised learning.

Neural Network with supervised learning

The ANN is trained by a supervised learning process: in the training phase the network processes all the pairs of input/output presented by the user, so called training set, learning how to associate a particular input to a specific output. Any pair of data in the training set is presented to the system a quantity of time determined by the user a priori. The learning step is based on the Error Back Propagation (EBP) algorithm [5]. The weights of the network are updated sequentially, from the output layer back to the input layer, by propagating an error signal backward along the neural connections according to the gradient-descent learning rule. Errors are then propagated back through the system, causing the system to adjust the weights which control the network. Those changes required to create a successful network constitute a process wherein the "art" of neural networking occurs.

Neural Network with unsupervised learning
Kohonen's Self-Organizing Map (SOM) [6] is a simple analogy of the human brain's way of organising information in a logical manner. It consists of one layer of neurons and uses the method of competitive learning with "*winner takes all*" logic. Kohonen's Self-Organizing Maps consist of one layer of neurons organized in one, two and multi-dimensional arrays (Figure 1). Each neuron has as many input connections as there are number of attributes to be used in the classification. All the neurons in the map are interconnected and each neuron influences others which are into its neighbourhood. The lateral coupling of the neurons is thought as a function of the distance in two ways: excitatory and inhibitory. The excitatory is in a short range up to a certain radius, and the inhibitory surrounds the excitatory area up to a bigger radius. A cluster or bubble around one particular node of the network is formed due to the lateral coupling around a given cell. The primary input determines a "winner" node, which will have a certain cluster, and then, following the input, the winner node with its surrounding cluster or neighbourhood will adapt to the input. The training procedure consists of finding the neuron with weights closest to the input data vector and declaring that neuron as the winning neuron. After finding the winner, the next step is to update the weights' vector of the neurons, the training algorithm is iterative and this procedure is repeated until a stop criterion is reached.

3 Artifacts

In X-ray CT image, artifacts are any discrepancy between the CT numbers represented in the image and the expected CT number based on the linear attenuation coefficient. The presence of artifacts in image degrades his quality, hiding areas of pathology: usually they appear as geometrical inconsistencies, blurring, streaks or inaccurate CT numbers. It is necessary to know causes in order to prevent them. Some causes are patient motion, beam hardening and metallic object.

Patient motion artifacts are caused by voluntary or involuntary patient motion. If motion occurs during the scan the computer is unable to place the correct CT Number into a matrix, so the image appears shaded or with streaked objects. Methods to reduce patient motion artifacts include patient immobilization or reduction of scanning time.

Beam hardening artifacts are produced by equipment malfunctions, such as a change of X-ray energy. This kind of artifacts can be reduced with a filter that ensures the uniformity of the beam at the detectors.

Metallic artifacts are caused by the presence of metallic objects such dental fillings, surgical clips, and electrodes. They appear as streak artifacts on the image. One way to prevent this kind of artifacts is expanding the CT number scales. In order to reduce them, it is possible to use post-reconstruction algorithm.

After an operation, radiotherapy it is necessary in order to reduce significantly local relapsed. To elaborate the treatment plan the patient is undergone to a tomographic test. In order to identify the origin, three metallic “**reperi**” are put on patient skin in three aligned points on a plane. These ‘metallic reperi’ are located by a laser system and they cause artifacts.

Artifacts are the major cause of CAT images' degradation and they could affect the accuracy of the diagnosis. The presence of these reperi is indispensable, but it produces metallic artifacts that changes radiographic study. There is another kind of metallic artifacts caused by the application of small metallic pieces on patient skin used to locate area to irradiate or to mark the presence of important details useful for the treatment study (for example cicatrices). Then assigned task is to obtain an image as like as image without artifacts.

4 Artifacts Removal

Medical image processing and understanding allows to optimise an increasing number of tasks in terms of treatment planning in radiotherapy. In previous work the authors

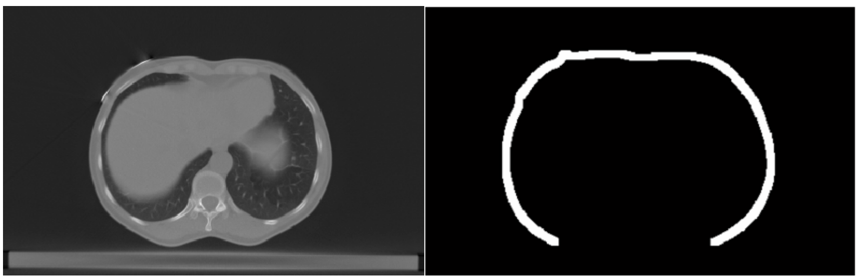

Fig. 3. Region of interest and its edge maps

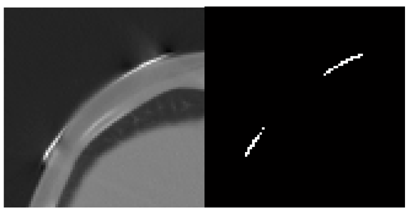

Fig. 4. Region of interest and its segmentation

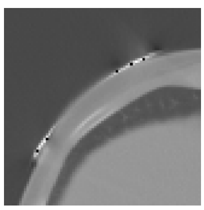

Fig. 5. Region of interest and its centroids

Fig. 6. The three investigated classes

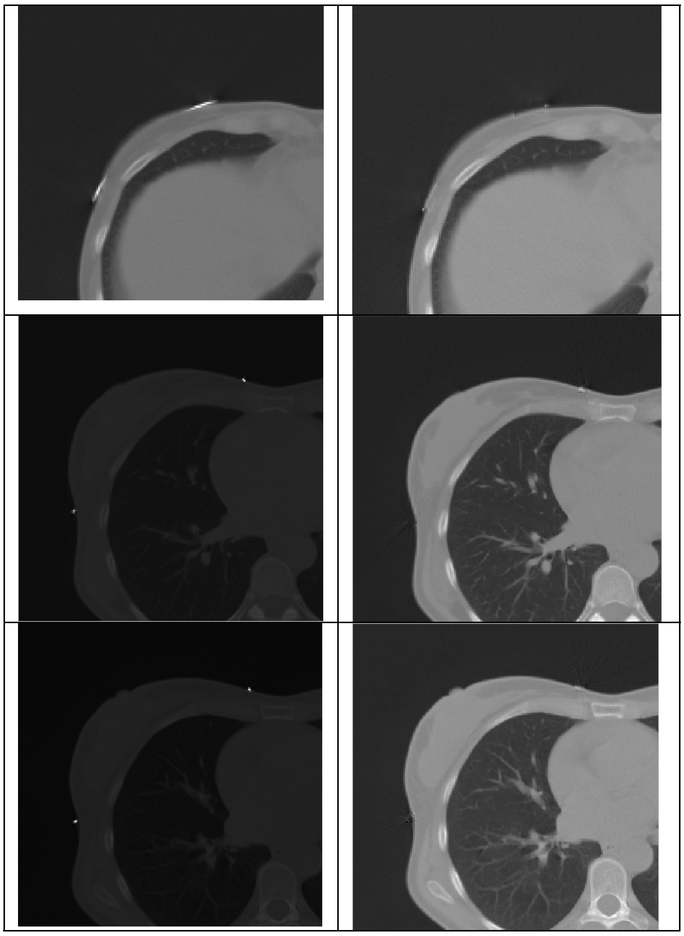

Fig. 7. Original on the left and processed images on the right

have already addressed some problems related PLATO systems and implemented algorithms to improve its performance [1]. At the same time there are several approaches in literature about methods to remove metallic artifacts in tomographic images by means of morphological operators, erosion and dilation, but the main interesting approach related to our work seems to be presented in [7]. We have tested an approach based on morphological operators on available dataset but results are not optimal. Therefore the algorithm developed uses neural networks. The tomo-graphic image data set used consists of 12 cases with artifacts and one without them used such as validation set: each one includes 60 slices, about 20 of them are damaged by artifacts' presence. In order to locate points on which execute the removal, it is necessary to reduce the analysis only to patient perimeter. In fact, the first step consists of region of interest selection, represented by patient perimeter: this is possible by means of an image thresholding, followed by edge detection.

Beginning from the obtained mask, another thresholding is executed in order to highlight corrupted pixels because of the artifacts' presence: corrupted pixels are that belong to the mask and that have an intensity value superior to 300 HU.

Then, it is executed a clusterisation of the obtained pixels by means of an unsupervised neural network. The number of cluster is determinated by of pixel obtained by means the thresholding: for each six pixels is set one cluster.

Centroid are classified applying a control on the angular coefficient of the line tangent to perimeter calculated for the considered point. There are chosen three classes of artifacts based on position along the border.

For each one class it is implemented a supervised neural network that takes in input a window (7x7 pixels) centred on artifact and gives back the corresponding window without artifact. The network is a Back Propagation with 2 hidden layer with 200 and 100 neurons respectively. The original window is replaced with the window obtained by the output of the network. Results are shown in Figure 7.

5 Experimental Results

To evaluate global result of artifacts removal differential Dose Volume Histogram (DVH) of treatment planes executed before and after removal are compared. DVH is

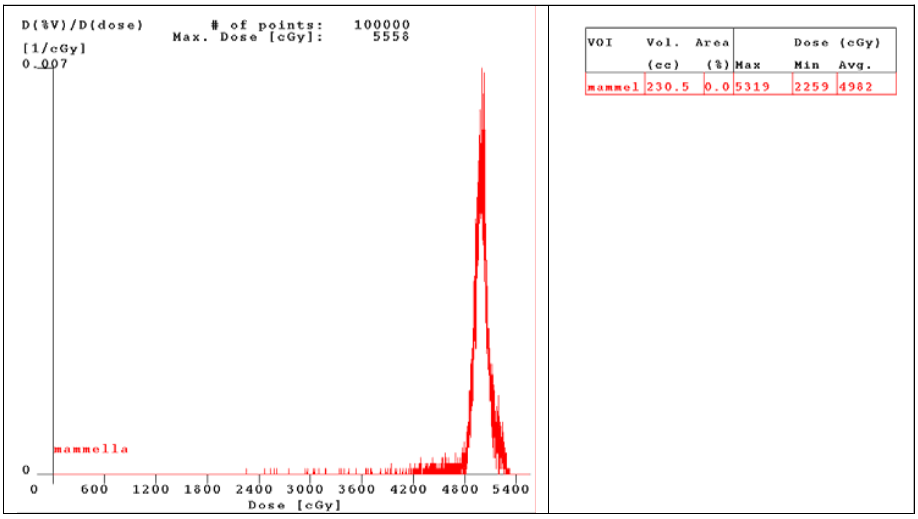

Fig. 8. DVH photons' fields with artifacts

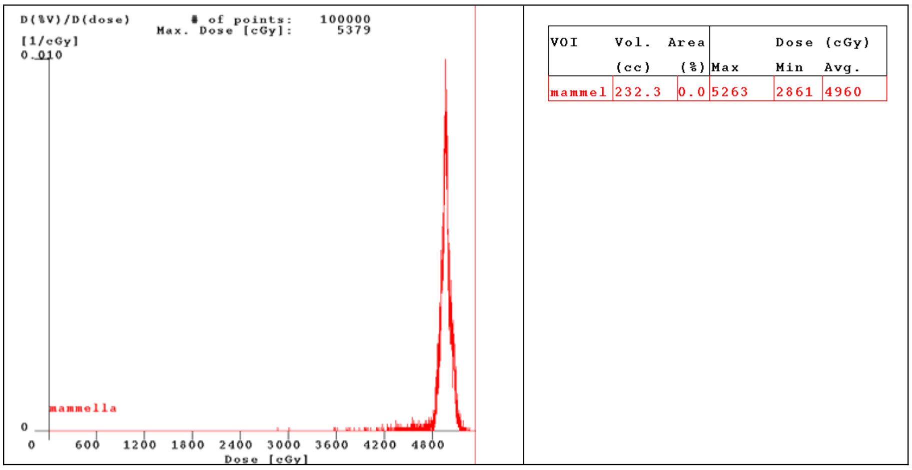

Fig. 9. DVH photons' fields without artifacts

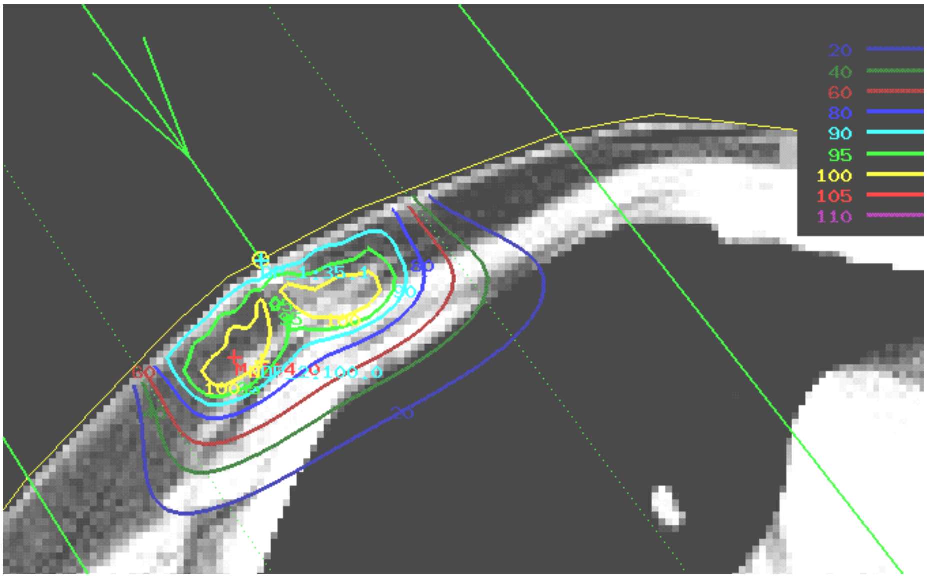

Fig. 10. Iso-dose lines for electrons' field after artifacts removal

a kind of graphic evaluation of treatment planes that is systematically used in all radiation therapy centres. Differential DVH represents the dose distribution (with a bell-shaped and average equal to medical prescription). A good treatment, with homogeneous dose supply in all interested volume, is represented by a differential DVH with a bell very narrow around its mean value.

Photons’ fields

In two–field tangential photons beams plan with modified DVH, the maximum value of dose decreases from 5319 to 5263 cGy (this value is on the skin at the field entrance and therefore outside of treatment volume). Moreover the minimum value of breast dose increases from 2259 to 2861 cGy, that is from 45% to 57% of prescription, obtaining a more homogeneous DVH. Following figures represent DVH in comparison to each other where “mammella” means breast.

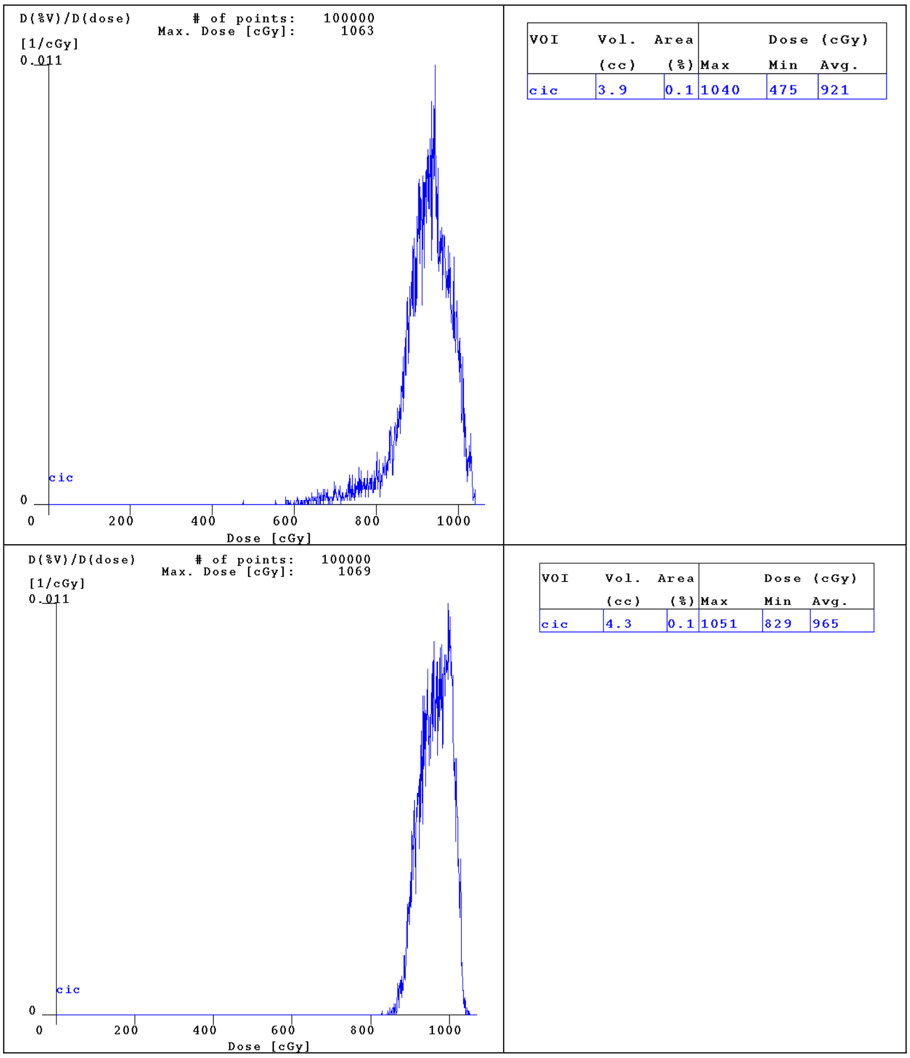

Fig. 11. DVH electrons' fields with (upper figure) and without (lower figure) artefacts

Electrons' field

In direct field of electron beam plan the dose differences between central area and lateral area of treatment volume decrease considerably as it is shown in Figure 10.

Consequently, in DVH evaluation, for the same maximum dose value, a clear increasing of minimum dose value in treatment volume is obtained from 475 to 829 cGy, that is from 48% to 83 % of prescription. Therefore histogram tail reduces to low dose values obtaining a more homogeneous DVH than previously. Moreover, for the same normalisation point, the new average dose value in treatment volume where "cic" means cicatrices, is higher than 4% compared to the previous.

6 Conclusions and Future Work

In this paper we have addressed the problem of removing by means of supervised and unsupervised neural networks algorithms some metallic artifacts produced by reperi in their neighbours in CT images. Experimental results, shown quantitatively in terms of electrons and photons fields DVH, encourage both the research in this area and the application of the implemented algorithm to a larger number of cases to validate that the dosimetric evaluation of planes could be more alike to real treatment, since patient does it without any metallic wire.

References

1. Vitoantonio, B., Giuseppe, M., Giuseppe P.: Evolutionary Approach to Inverse Planning in Coplanar Radiotherapy. Image Vision Comput. 25(2): (2007) 196-203
2. Vitoantonio B., Giuseppe M., Mario M.: A Neural Network Approach to Medical Image Segmentation and Three-Dimensional Reconstruction. ICIC (1) 2006: 22-31
3. Knowles, J., Corne, D., Bishop, M.: Evolutionary Training of Artificial Neural Networks for Radiotherapy Treatment of Cancers, Proceedings of 1998 IEEE International Conference on Evolutionary Computation, Alaska, (1998) 398–403.
4. Timp, S. , Karssemeijer, N.:A New 2D Segmentation Method Based on Dynamic Programming Applied to Computer Aided Detection in Mammograph, Medical Physics 31 (2004) 958–971.
5. Haykin S.: Neural Networks: A Comprehensive Foundation (Prentice Hall - 2nd Edition)
6. Kohonen, T.: Self-Organization and Associative Memory, Springer-Verlag, Heidelberg, (1988)
7. Wei, J.K., George, A. S., Hsi,W.C., Ringor,M., Lu,X.Y.: Dosimetric Impact of a CT Metal Artifact Suppression Algorithm for Proton, Electron and Photon Therapies Jikun Wei et al Phys. Med. Biol. 51 (2006)5183-5197