Decision Support System for radiotherapy based on Fuzzy Cognitive Maps

Chrysostomos D. Stylios
Laboratory for Automation & Robotics, University of Patras, 26500 Rion, Patras, GREECE
Email: stylios@ee.upatras.gr

Pamela C. Georgopoulos
Laboratory for Automation & Robotics, University of Patras, 26500 Rion, Patras, GREECE
Email: pageorg@ee.upatras.gr

Peter P. Groumpos
Laboratory for Automation & Robotics, University of Patras, 26500 Rion, Patras, GREECE
Email: groumpos@ee.upatras.gr

Abstract

During radiotherapy many decisions have to be made and the development of an advanced decision support system that take into consideration different and discipline factors in determining the dose calculation for radiotherapy treatment would be very useful. The implementation of Fuzzy Cognitive Maps (FCM) for decision-making issues in radiotherapy is proposed. FCMs can handle with imprecise, uncertain information and can be used as a decision making model determining radiation dose and other related quantities.

Keywords: Fuzzy Cognitive Maps (FCM), Decision Support, Radiotherapy.

1 Introduction

Radiotherapy is the treatment of pathological illness and elimination of infected cells applying ionizing radiation. For therapy of cancer cells, photons or electrons are used and the major issue is the determination of radiation dosage distribution. Different factors are taken into consideration using empirical methods. It is necessary to know how a tumor will be destroyed by irradiation and how surrounding healthy tissue is likely to be adversely affected by the applied radiation dose.

Doctors have to make many decisions on the implementation of radiation based on many different factors that some are complementary, other similar and other conflicting. On the other hand each factor determines the selection of the dose and finally the result of the therapy with a different degree.

In this research work the soft computing technique of Fuzzy Cognitive Maps is used to model the decision making process in radiation therapy. FCMs have been used to model complex systems that involve different factors, states, variables and events [1]. FCMs can integrate and include in the decision making model the partial influence of controversial factors [8], taking under consideration their causal effect in recalculating the value of all the causal concepts that determine the radiation dose, keeping it in a minimum level and at the same time having the best result in destroying tumor and with the minimum injuries to healthy tissues [5].

2 Fuzzy Cognitive Map model

Fuzzy Cognitive Maps have been successfully used to model complex systems such as the radiation treatment decision-making system. Fuzzy Cognitive Maps can be used to develop a decision support system and they are based on human reasoning.

Fuzzy Cognitive Maps (FCM) use a symbolic representation to describe and model complex systems. FCMs are consisted of concepts that illustrate different aspects of the model and behavior of the system and these concepts interact with each other showing the dynamics of the system. FCM structures can be used to represent qualitative and quantitative models. FCMs integrate the accumulated experience and knowledge on the causal relationship between factors, characteristics, components of the system; due to the way they are constructed, using human experts that know the system and its behavior [11].

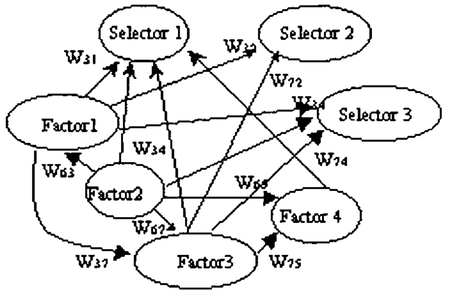

Figure1.The FCM model with selectors and factors for concepts

The Fuzzy Cognitive Map knowledge is reflected in the structure of concepts and their weighted interconnections, each concept represents one of the key-factors of the modeled system and it is characterized by a number A_i that represents its value. Relationships between concepts have three possible types: either express positive causality between two concepts ($W_{ij} > 0$) or negative causality ($W_{ij} < 0$) or no relationship ($W_{ij} = 0$). The value of weight W_{ij} indicates how strongly concept C_i influences concept C_j. The value A_i of each concept C_i is calculated by the following rule:

$$A_i^{t+1} = f(\sum_{\substack{j=1 \\ j \neq i}}^{n} A_j^t W_{ji}) \qquad (1)$$

Namely A_i^{t+1} is value of concept C_i at step t+1, A_j^t is the value of concept C_j at step t, and W_{ji} is the weight of the interconnection from concept C_j towards concept C_i and f is a threshold function. The new value A_i^{t+1} of concept C_i is determined by the influence of the connected concepts C_j with the corresponding weight, showing the effect of the change in one concept on the other concepts [10].

The FCM model for the radiotherapy decision making model is consisted of concepts that are the **factors** that are taking into consideration in determining the **selectors** that are the concepts determining the final decision. FCM model not only represent all the factors but in addition to this the existing relationship among factors because factors may be dependable and there is an influence of one factor to the others. Moreover, factors influence the degree of selectors and the value of each selector can be thought as the output of the system. In fact, when a doctor makes decision on the radiation therapy he determines the selectors and their values, the FCM decision-making model will do the same. Figure 1 illustrates a generic FCM decision-making model.

3 Radiotherapy Factors

Many different treatment techniques have been developed to determining the distribution dose in radiation therapy. The most important clinical requirement is the delivery of strongly nonuniform beams on the patient from arbitrary directions. In complex tumors the number of beams required to eradicate the tumor without severe injury to normal tissues is quite high but in simple target geometries fewer beams are sufficient, and in cases with small tumors the classical uniform beams will do nicely. Calculating doses to radiotherapy patients involves a trade-off between computation time and accuracy.

Therefore, a variety of factors have to be taken into consideration in the selection of radiation therapy [2,9]. These may include:

- The depth at which the tumor is located and the size of the tumor
- The type of tissue with the problem, as well as the type of tissue that surrounds the tumor.
- The existence of radiation-sensitive organs within the treatment volume, such as: eyes, larynx etc.
- Body thickness of the patient.
- The number of radiation fields that must be used and the daily dosage on the tumor based on the biological damage of the healthy subcutaneous tissue.
- Cost. It includes cost of equipment, cost of shielding, cost of usage of space.
- The length of time for administering treatment.
- Amount of secondary (scattered) radiation accepted by the patient.
- Degree of difficulty in repeatability.

On the other hand, a good distribution of the radiation on the tumor, as well as to protect the healthy tissues have to achieved taking into consideration the following **selectors** :

- Selection of appropriate size of radiation field.
- Increase of entry points of the beam
- Selection of appropriate beam directions.

- Selection of weight of each field (dose contribution from individual fields).
- Selection of appropriate energy and type of radiation (x-rays, ?-rays, electrons).
- Modification of field with blocks or multileaf collimators and/or wedge filters.
- Processing of the outline of the patient additing a compensator in place of the missing tissue.
- Use of stationary beam therapy or rotation therapy.

The radiation therapy planning scheme for the final dose distribution in the target tumor and surrounding tissues is based on the values of selectors, which is influenced by the values of the parameters-factors in order to determine the best treatment plan [3,7].

The kind, nature and number of the parameters-factors that have to be taking under consideration in determining the radiation treatment bring up the fuzziness, the complexity and the uncertainty of the model. These are characteristics and qualities of the Soft Computing technique of Fuzzy Cognitive Maps.

4 Development of FCM model for radiotherapy

Many factors and characteristics are taking into consideration to determine the radiotherapy qualities. These factors and characteristics are the concepts of the Fuzzy Cognitive Map model that is used to model the decision-making procedure of the radiotherapy treatment. The number of concepts that will consist the Fuzzy Cognitive Map model of the radiotherapy treatment system are 34 concepts. Concepts of FCM belong to 2 categories: inputs concepts and output-selector concepts. Input concept represent factors with given or measured or desired values and taking their values from the real system and/or sensors and their measurements, with transformation to fuzzy interval. On the other hand, there are the output concepts that their value is influenced and determined by the value of the input concepts with the corresponding causal weight and the decision making process is the determination of their value. The input nodes are the factors taken into consideration and the values of the output concepts lead to the final decisions.

Values of concepts are described using linguistic variables such as high, medium and small and they are transformed in numerical values using a defuzzification method. Or concept may represent continuous values and in this case the concept value is calculated as the percentage of the real value. Another case is when concepts represent events and discrete situations, in this case there is border (0.5) that determines which event is activated. All the values of concepts in the FCM belong to the interval [0,1]. The following concepts consist the Fuzzy Cognitive Map:

C1: Type of radiation. This concept represents three discrete values.
C2: Quality of radiation. It represents the quality of radiation, so it takes continuous values.
C3: Size of radiation field(s). The size of radiation field is categorized into five fuzzy categories.
C4: Single or multiple field combinations. This concept represents two discrete conditions.
C5: Beam direction(s)
C6: Weight of each radiation field.
C7: Stationary versus rotation - isocentric - beam therapy. It represents two discrete conditions.
C8: SSD (used in non isocentric techniques).
C9: Wedge filters.
C10: Cerrobend blocks versus multileaf collimators. This concept represents 2 discrete conditions.
C11: Compensating filter or bolus.
C12: Patient immobilization.
C13: 2D versus conformal (3D) radiotherapy.
C14: Depth of tumor. This concept can be scaled in five fuzzy values.
C15: Size of tumor. It can be scaled in seven fuzzy values.
C16: Shape of tumor. It represents the degree of irregularities scaled in three fuzzy values.
C17: Location of tumor - size of cross section.
C18: Regional metastasis of tumor. This concept can be scaled in five fuzzy values.
C19: Type of tissue(s) included in irradiated volume inhomogeneities. It represents the degree of inhomogent scaled in 4 fuzzy values.
C20: Dose uniformity within target volume. It is important and takes desired fixed value.
C21: 90% isodose surrounding treatment volume. It is important and takes almost fixed value
C22: Radiation sensitive organs within irradiated volume. This concept represents the abutting on sensitive organs scaled in 3 fuzzy values.
C23: Skin sparing. This concept can be scaled in five fuzzy values.
C24: Patient thickness. This concept can be scaled in five fuzzy values.
C25: Patient contour. This concept can be scaled in five fuzzy values.

C26: Damage to healthy tissue in irradiated volume. It is scaled in three fuzzy values.
C27: Scattered radiation received by patient. This concept can be scaled in five fuzzy values.
C28: Repeatability- flexibility of treatment setup. It is scaled in three fuzzy values.
C29: Time required for treatment procedure or planning. It is scaled in five fuzzy values.
C30: Cost of equipment, shielding and space. This concept can be scaled in five fuzzy values.
C31: Almost perfect match of beam to target volume. It is scaled in three fuzzy values.
C32: Edge Effect. Value of this concept can be scaled in three fuzzy values.
C33: Tumor position regarding center of contour cross section. It is scaled in 3 fuzzy values.
C34: Irradiation of one side of skin surface.

Concepts C1 to C13 are the output concepts and concepts C14 to C34 are the input concepts. Values of the output concepts are determined: what kind of therapy is chosen, the depth, if there are multiple or single fields, if wedge filters are used, etc.

Between concepts the weighted arc shows the influence of one concept to another. Experts using linguistic values describe the weights between the concepts. There are causal interconnections from input concepts towards output concepts. The radiation decision making system is complex because there exist interrelations among the input concepts and among the output concepts. Furthermore there are causal relationships from output concepts towards the input concepts that create cycles of causality.
Fuzzy Cognitive Map model of the decision-making radiotherapy system is developed, it is consisted of 34 concepts and 377 interconnections with numerical weights that produced of the defuzzification of linguistic fuzzy values.

5 Conclusions

Fuzzy Cognitive Maps were used to developing a decision support radiotherapy system. All factors that determine the decision procedure were presented that made apparent the complexity of the system. An advanced model was developed that take under consideration all the complementary and controversial factors. These are the strengths of Fuzzy Cognitive Maps. A Fuzzy Cognitive Map was developed that creates a sophisticated decision support system for the radiotherapy system.

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