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CT-guided microwave liver tumors ablation and automatic adjustment of frequency

BOUHARATI Imene [1,2], BABOUCHE Farid [1], BOUHARATI Khaoula [1]

Abstract. Objective. Primary tumors such as hepatocellular carcinoma (CC) treated by the use of microwaves has the advantage in its ability to overcome the large heat sinks inherent in this vascular organ. Also, it offers the possibility of treating larger tumors with fewer applicator placements in less time compared to radiofrequency ablation techniques. However, the transmission of electromagnetic energy is determined by the dielectric permittivity of biological tissues. This one is very complex to model because it is a function of frequency, temperature and other factors specific to the tissues. Add to this, much of the energy radiated by antennas is in absorbed by biological tissue in areas near the antenna and cannot propagate as a plane wave. In this case, the penetration depth calculations take into account the attenuation of the tissue. In this study, we propose the use of a 3D radiological image of the carcinoma for the geometric calculation of its center mass. This image should also provide the spatial distribution of density across the tumor. **Methods.** The introduction of the scano-guided probe makes it possible to reach its location with great precision. From the distribution of the tissue density, the parameters characterizing the thermal properties are calculated. An automatic system regulates the frequency (radiated energy) and the time which will then be adjusted during the operation according to the pre-set parameters. **Results.** The predefined norms relating to the nature of the tissue, the propagation of the temperature through the volume, the necessary time, with a heating frequency prefixed, that leads to the cellular destruction are introduced in algorithm. During the process of tumor destruction, the thermal conductivity varies. This variation is taken into account in the output of the system which acts on the readjustment of temperature and the regulation of time.
Conclusion. This tool offers the benefit of accuracy, overheating, optimization of tissue conduction and heat loss. Existing models are based on approximations in electromagnetic-thermal interaction estimates. We propose to introduce in the frequency and time adjustment calculation software, a fuzzy logic system that supports these uncertainties inherent to the complexity of the tissue to be treated.
Keywords: hepatocellular carcinoma, microwaves, radiofrequency ablation, radiology, radiated energy, fuzzy logic.

Introduction

Hepatocellular carcinoma (hepatocellular carcinoma) is the most common cancer in adults. This cancer is the second most common cause of cancer mortality and the sixth most common in the world1.

1. Faculty of Medicine, Ferhat Abas Setif1 University, Algeria
2.Intelligent Systems Laboratory, University Ferhat Abbas Setif1, Setif, Algeria
Corresponding author: Bouharati Imane
Email: sbouharati@yahoo.fr
Tel: +21366137459

It accounts for 85-90% of primary liver cancers. Half a million people worldwide die from HCC annually, demonstrating a poor prognosis for this cancer[2-3]. The incidence of this cancer is increasing rapidly in Western countries. What can explain this growth are its risk factors such as hepatic steatosis, viral hepatitis and alcohol[4]. This type of cancer takes different forms. Some begin with a single tumor that develops to occupy a large volume in the liver. The other type is characterized by the formation of several nodules distributed throughout the volume of the liver in the form of multiple tumors (cirrhosis).

If the surgical procedure remains the most recommended means in the removal of the liver tumor, sometimes it is necessary to proceed to ablation by non-surgical techniques[5-6]. This is recommended, for reasons of multiple metastases, difficulty of access to the tumor from in anatomical point of view, for inadequate liver functions and for medical comorbidities[7-8]. Among these techniques, this article relates microwave ablation.

The problem is the complexity of the system. The heterogeneous distribution of tissue density across the tumor mass, the 3D geometric no uniformity of the tumor and also the variability of thermal conductivity during the process of tissue transformation by temperature effect are very complex. We propose the determination of all these parameters previously. Also, by guided introduction of the probe to the center of mass whose coordinates are previously fixed, the thermal propagation will be optimal in each point at a given moment. As all these parameters are far from being exact, a fuzzy inference system is proposed from their modeling.

Physical mechanism

The technique of tumor ablation by microwaves as therapy consists of thermal diffusion in order to destroy abnormal tissues. As the molecule of water is a bipolar molecule seen the geometrical configuration of its atoms, the distribution of electric charges is non-uniform. Under the effect of electromagnetic waves in a specific frequency range, the molecule H_2O is in permanent rotation where the dipoles are exchanged at high frequencies. By friction, the temperature increases which causes necrotic coagulation and thus cell death[9-10]. Also another factor can intervene in this case, it is the ionic polarization. Here, it is when the ions move under the effect of the electromagnetic field and strike while producing heat by kinetic energy conversion[11]. The advantage of microwaves over radiofrequencies is that the temperature propagates through the living tissue regardless of its electrical conductivity. However, it presents the disadvantage of the need for the introduction of multiple insertions in view of the non-uniformity of the tumor form as well as the overheating of the probe shaft[12].

Several studies have modeled the thermal conductivity of tissues. These models refer to the cylindrical hot-wire technique in cylindrical coordinates whose equation is[13]:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

The solution of this equation is given in the form[14]:

$$T - T_i = \frac{-q'}{4\pi k} E_i\left(\frac{-r^2}{4\alpha t}\right)$$

Where T is the temperature, t is the time, r is the position and α is the thermal diffusivity of the medium, k is the thermal conductivity and q' is the linear source of heat (Wm-1). The problem is these equations describe the behavior of thermal diffusion below 55 ° C. beyond; the phenomenon takes other steps to the cell transformation by thermal coagulation. It then becomes very difficult to model[15].

Used systems

Different types of microwave systems have been used recently. They differ in their frequency range used. Some are equipped with gas or liquid chillers. This cooling provides for overheating of the duct and therefore the burning of the skin and facilitates the concentration of heat on the tip allowing the destruction of a large tumor area[16-17]. Thus, the use of a cooled shaft antenna minimizes major complications that may occur[18]. Despite several techniques used, some tumors remain difficult to access or difficult to visualize the example of tumors whose distance is less than 5mm of vital tissues. Ablation at these locations was contraindicated for high risk of complications. High accuracy is required in this case.

Although the image-guided microwave liver ablation technique is widely used, challenges remain in this area. Today, imaging-guided technologies with either CT, MRI or ultrasound guidance each have their limitations, although ultrasound guidance remains the most widely used because it allows real-time monitoring[19-21]. The 3D geometrical shape of the tumor is far from uniform. Also, the density distribution is also heterogeneous across the tumor volume. These factors make that in the case of microwave ablation uses multiple insertions. To overcome these difficulties, another approach is proposed. The first step is to acquire a 3D image of tumor volume using conventional imaging. Record the density distribution across the volume. Then by algorithmic calculation performed by an embedded calculator determine the center of mass. This point determines the optimum for the thermal diffuser to reach the entire volume at the same time. During the thermal diffusion process, changes in cellular state occur. This can cause variations in thermal conductivity and therefore propagation. High temperature causes thermal denaturation and causes necrosis of thermal coagulation in tissues[22-24]. In order to generate valid results, it is necessary to introduce in the hyperthermia or thermal ablation models precise values of these thermal properties[25]. During the phase of cell death by heating, a transformation of the conductive properties takes place. This conductivity is a function of the temperature, the distance of the source, the nature of the tissue itself, the frequency used and the time. The phenomenon is very complex to model it numerically. In this vein, this study deals with a system of regulation and control of the temperature provided by the probe as a function of time and the nature of the tumor tissue[26-29]. We consider these variables to be uncertain and imprecise. The application of fuzzy inference reasoning is adequate.

Fuzzy model

Fuzzy inference analysis is a mode of approximate reasoning. Being a branch of mathematics, it imitates human reasoning. Such a title is considered as technical artificial intelligence[30]. This mode of data analysis makes it possible to take care of the uncertainties and inaccuracies inherent to the nature of the data. Numeric variables are converted to linguistic variables. The operations are performed by logical operators of type *'and'* ‘*or’* or both[31].

In this case, the fuzzy system is constructed with five inputs (temperature, distance, nature of the tissue, frequency and the time) and two outputs (action on the temperature and time). Each input or output variable are fuzzyfied. This operation consists of converting numerical values into linguistic values. A database is built from the real values of each parameter. It is a question of making the correspondence between the inputs and the outputs in the form of rules of inference (If ... Then). The result at the output of the system is obtained by defuzzyfication which consist to extract a net value which acts on the adjustment of the control of the temperature and the time[32].

Outputs = f (T,D,N,f,t)

Where : T (Temperature)
D (Distance)
N (Nature of tissue)
f (frequency)
t (heating duration)

Proposed system

The system comes down to a schematic of five inputs and two outputs designed by Matlab 10. Figure 1.

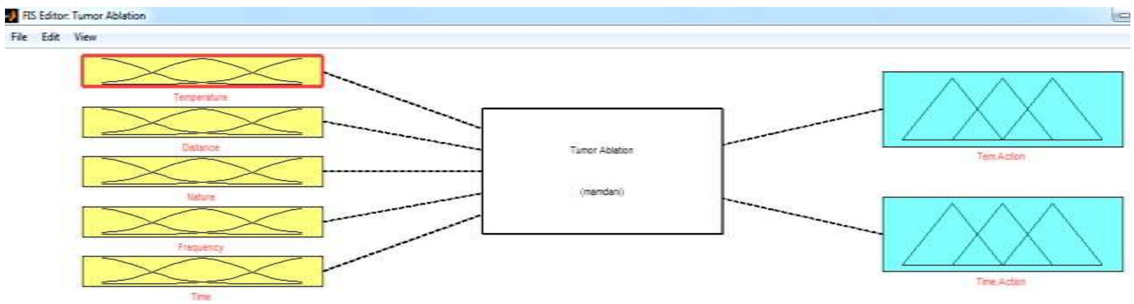

Figure 1. Schematic of the proposed system

Variables fuzzyfycation

The input variables are:

- *T* (temperature of the probe necessary for the destruction of the tumor cells) is fuzzyfied in three fuzzy intervals (low, medium, high).
- *D* (distance between the tip of the probe and the point to be destroyed) is fuzzyfied in three fuzzy intervals (near, medium, distant).
- *N* (nature of the tissue that is related to its state and therefore its thermal conductivity) is fuzzyfied in three fuzzy intervals (good conduction, average conduction and poor conduction).
- *f* (the electromagnetic frequency applied to the probe) is fuzzyfied in three fuzzy intervals (low, medium and high).
- *t* (heating duration) is fuzzyfied in three fuzzy intervals (short, medium and long).

The output variables are:

- *AT* (action on the temperature) is fuzzyfied in three fuzzy intervals (increase, stabilize, decrease).
- *At* (action on the time) is fuzzyfied in three fuzzy intervals (short, fixed, long)

```
[System]
Name='Tumor Ablation'
Type='mamdani'
Version=2.0
NumInputs=5
NumOutputs=2
NumRules=63
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='Temperature'
Range=[50 90]
NumMFs=3
MF1='Low':'trimf',[50 60 70]
MF2='Medium':'trimf',[60 70 80]
MF3='High':'trimf',[70 80 90]

[Input2]
Name='Distance'
Range=[0 6]
NumMFs=3
MF1='Near':'trimf',[0 1.5 3]
MF2='Distant':'trimf',[3 4.5 6]
MF3='Medium':'trimf',[1.5 3 4.5]

[Input3]
Name='Nature'
Range=[0 4]
NumMFs=3
MF1='Good':'trimf',[0 1 2]
MF2='Average':'trimf',[1 2 3]
MF3='Poor':'trimf',[2 3 4]

[Input4]
Name='Frequency'
Range=[0 4]
NumMFs=3
MF1='Low':'trimf',[0 1 2]
MF2='Medium':'trimf',[1 2 3]
MF3='High':'trimf',[2 3 4]

[Input5]
Name='Time'
Range=[0 4]
NumMFs=3
MF1='Short':'trimf',[0 1 2]
MF2='Medium':'trimf',[1 2 3]
MF3='Long':'trimf',[2 3 4]

[Output1]
Name='Tem.Action'
Range=[0 4]
```

```
NumMFs=3
MF1='Increase':'trimf',[0 1 2]
MF2='Stabilize':'trimf',[1 2 3]
MF3='Decrease':'trimf',[2 3 4]

[Output2]
Name='Time.Action'
Range=[0 4]
NumMFs=3
MF1='Short':'trimf',[0 1 2]
MF2='Fixed':'trimf',[1 2 3]
MF3='Long':'trimf',[2 3 4]
```

An example of temperature fuzzyfication is shown in Figure 2.

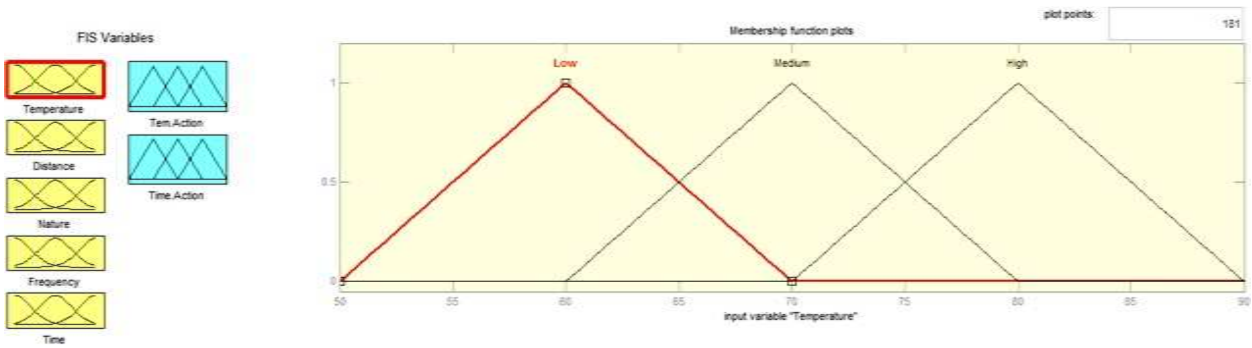

Figure 2. Fuzzyfication of temperature variable

Base rules

The general form of an inference rule is (If ... Then). This involves making connections between the inputs and outputs of the system. The base of the rules can contain all possible combinations encountered. From values entered at the input, resultant values at the output. The values recorded at the output must act on the automatic variation of the input parameters in the adjustments according to the needs to reach the expected result in tumor ablation.

Result

The base of the rules is established according to the predefined norms relating to the nature of the tissue, the propagation of the temperature through the volume, the necessary time, with a heating frequency prefixed, that leads to the cellular destruction.

During the process of tumor destruction, the thermal conductivity varies. This variation is taken into account in the output of the system which acts on the readjustment of temperature and the regulation of time. Application example is illustrated in Figure3

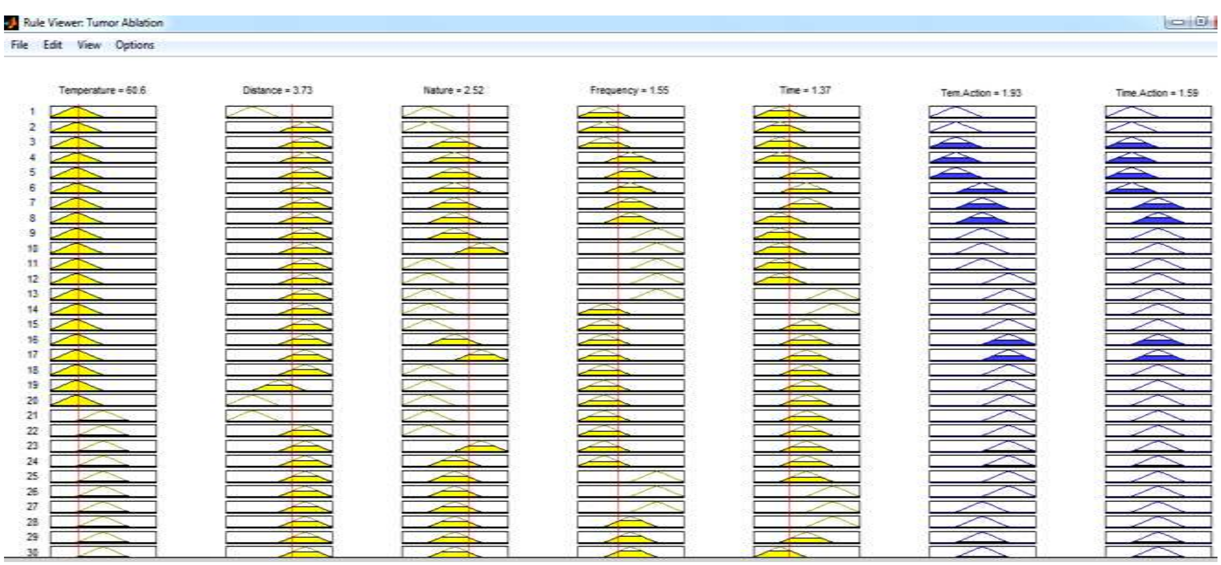

Figure 3. Application example

Conclusion

The propagation of heat through the tumor volume is a function of several factors. The set of parameters that are imprecise make it must always hold the temperature and the time. To do this, the uncertainties related to the nature of these factors are taken into account in a fuzzy system. The proposed system makes it possible to introduce a pre-established algorithm comprising the variations of the propagation of temperature as a function of time, the distance of the source, the frequency and the variation of the thermal conductivity generated by the cellular transformation. These variations are fuzzy and imprecise an action at the output of the system to act on the regulation of the input parameters. Automatic adjustment allows optimization of the system for a precise result. This can be a tool to help regulate and optimize tumor ablation using microwaves.

Conflict of interest

The authors declare that they have no conflict of interest

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