AUTOMATIC HUMAN BODY SEGMENTATION USING MEAN-SHIFT CLUSTERING AS ASSISTANCE IN THE HYPERTHERMIA TREATMENT PLANNING

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The article deals the human body segmentation technique which supports hyperthermia oncology treatment planning. According to the inner structure of the tumor the applicator needs to be placed in the right direction. We used the automatical segmentation using mean-shift clustering algorithm in comparison with the segmented image data evaluated by the medical expert. The data was obtained with the commercial segmentation software 3D-DOCTOR. The quality of the segmentation can be essential for not only for treatment planning but can also provide the feedback in clinician decision making.

Introduction

New medical imaging techniques such as the CT or MRI bring the possibility to reconstruct inner body organs from given slices. This can be very useful when radiotherapy, microwave or other energy radiating applicator needs to be precisely positioned to ensure that the energy is radiated into chosen place with no harm to the surrounding tissue.

The majority of commercial segmentation programs which are commonly used throughout hospitals use image recognition techniques based on histogram distribution. This approach is not accurate when we are looking for not only coarse division of the human body tissues. It can for example occur when we want to distinguish between the soft tissues and the solid bone tissues. It might be sufficient until we are looking for something more specific with less obvious changes in examined material.

For this reason, we propose the segmentation quality assessment process that can evaluate the correspondence between the clinician manually segmentation and artificial automatic mean-shift clustering algorithm. The algorithm accuracy matches the performance of the medical expert that participates in this study.

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1 Thermal Effects on Human Organism

Hyperthermic effects on living organism are not that simple matter [1] as it can be seen but here comes a variety of factors to deal with. We can divide them into two major groups; effects caused by blood flow in the tissue and effects of the heat shock proteins (HSP). On cellular level we can describe the heat shock proteins as agents which are protecting the cells and the whole organism from lethal hyperthermia expositions.

In mammals the effects of higher temperatures (up to 42°C) cause cellular damage caused by a denaturation of proteins. When this happens the cell protheosynthesis is terminated and apoptosis is induced.

Physiologically the thermal exposition in mammals happens together with fever when heat shock proteins come to action, this supports the hypothesis that the heat shock proteins are protecting the cells against high temperatures. In fact we still know very little about heat shock proteins as the fever sicknesses are as old as the humankind.

The other very important physiological parameter influencing tissue response to heat is the blood flow. At higher temperatures blood perfusion increases in many tumors and this effect is dependent on heating time, temperature and also tumor structure. Blood flow increases to improve tumor

oxygenation, but in most cases it is not sufficient because of the increased consumption of oxygen in heated tissue. When heating is terminated, blood perfusion and oxygenation slowly recover and how quickly this occurs appears to be tumor-specific. Similar physiological effects occur in normal tissues, but normal tissue has more sophisticated vascular structures to help the tissue deal with the higher temperatures. Heating tumors to higher temperatures typically causes a increase in perfusion during heating which is followed by vascular collapse and if sufficient, this will lead the tumor to necrosis. The speed and degree of vascular collapse depends on heating time, temperature and, of course, on the tumor.

The tumor vascular supply can also be exploited to improve the response to heat. Decreasing blood flow, using physiological modifiers or longer acting vascular disrupting agents prior to the initiation of heating can both increase the accumulation of physical heat in the tumor, as well as increase the heat sensitivity of the tumor.

2 Hyperthermia Oncology

Hyperthermia, also called thermotherapy, is a type of cancer treatment [2] in which body tissue is exposed to high temperatures (up to 42°C). It has been shown that high temperatures can damage and kill cancer cells, usually with lower injury to normal tissues. Damaging proteins and structures within cells is causing death of cancer cells by damaging proteins and their inner structures.

Hyperthermia is often used with other forms of cancer therapy, such as chemotherapy and radiation therapy. Hyperthermia may make some cancer cells more sensitive to radiation or harm other cancer cells that radiation cannot damage and it can also enhance the effects of certain cytostatics.

There are two main streams in hyperthermia thermotherapy depending on the area of the human body where the heat was applied. Thus, we have a local hyperthermia application and a whole body application.

In local hyperthermia, heat is applied to a small area, such as a tumor, using techniques that deliver energy to heat the tumor. Different types of energy may be used in this case including radiofrequency, microwave, or ultrasound.

Depending on the tumor location, there are several approaches to local hyperthermia: External approaches [2] are used to treat tumors in superficial area, which means that the tumors are not more than *30mm* below the skin. External applicators are often positioned around or near the appropriate region, and energy is focused on the tumor.

The internal method may be used to treat tumors close or near body cavities, such as the esophagus or rectum. Intracavitary applicators are placed inside the cavity and inserted into the tumor to deliver energy which dissipates into heat in the desired area.

Interstitial techniques are used to treat tumors deep within the body, such as brain tumors. This technique allows the tumor to be heated to higher temperatures than external techniques. Under anesthesia, intracavitary applicators are inserted into the tumor. Imaging techniques, such as ultrasound, may be used to make sure the probe is properly positioned within the tumor.

To ensure that the desired temperature is reached, but not exceeded, the temperature of the tumor and surrounding tissue is monitored throughout hyperthermia treatment. Using local anesthesia, the doctor inserts small needles with tiny thermometers into the treatment area to monitor the temperature. Imaging techniques, such as computer tomography, may be used to make sure the probes are properly positioned.

That is why we are interested in the image processing of the CT/MRI data which after process of segmentation enables us to create the model of inner organs affected by a tumor. Once we know the exact position of the tumor inside the body and the location of important body organs such as the pneumogastric nerve, the microwave thermotherapeutic applicator can be placed into the right position assuring that the microwave energy will be delivered directly into the tumor.

3 Hyperthermia Oncology Treatment Planning

Treatment planning for clinical hyperthermia requires precise determination of the tumor location as in case of radiotherapy, so the first step is a series of patient contours with the tumor volume indicated. CT or MRI is the most suitable source of such information. For lesions, the ultrasonic scan-

ning can be a satisfactory technique as well as visual inspection and palpation for identification of the circumference of many superficial tumors such as in chest wall. Nevertheless, to obtain the information concerning the depth of invasion the MRI or CT diagnostics is necessary.

Multiple consecutive slices contain probably the most complete and precise information available for any anatomical location. After obtaining MRI/CT slices, the process of data image segmentation will create a 3D volume of the tumor area, which is very useful when placing the thermometer probes. Before placing the microwave applicators for the hyperthermia oncology, certain simulations need to be run. These simulations are usually done in an electromagnetic field simulator. We are interested mainly in the heat propagation in and around the tumor in case there would be an area of the organ or nerve which can be critically damaged by the propagating heat from the tumor. Heat equation and modelling of its propagation is done in electromagnetic field simulator, when we import the segmented data into the design environment assigning each tissue a proper value of the complex permittivity. Complex permittivity of the tissue can be measured directly on the patient by invasive or non-invasive methods. The final result of this process is the model of the tumor with precise coordinates for placing the thermotherapeutic applicator. Moreover, we know how the heat energy will propagate in the surrounding tissue, leaving us more time to interact if the state of the patient goes wrong.

4 Data

We collected MRI slices through the whole human body in DICOM file format. From this slices, we choose the 20 representative slice images. Subsequently, these were evaluated by the medical expert. His expertise consisted in segmentation of the different part of the tissues represented by the slices, including bone, muscle, fat, air, and others. For this purposes, he used the 3D-DOCTOR commercial program. It is advanced 3D modelling, image processing and measurement software for MRI, CT, PET, microscopy, scientific, and industrial imaging applications.

5 Mean-shift Clustering Algorithm

The mean-shift algorithm is a nonparametric clustering technique which does not require prior knowledge of the number of clusters, and does not constrain the shape of the clusters. Given n data points of x_i on d-dimensional space, the multivariate kernel density estimate obtained with kernel $K(x)$ and windows radius h is

$$f(x) = \frac{1}{nh^d} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h} \right). \tag{6.1}$$

For radially symmetric kernel, it suffices to define the profile of the kernel $k(x)$ satisfying

$$K(x) = c_{k,d} k(\|x\|^2), \tag{6.2}$$

Where $c_{k,d}$ is a normalization constant which assures $K(x)$ integrates to 1. The modes of the density function are located at the zeros of the gradient function $\nabla f(x) = 0$.

The gradient of the density estimator is

$$\nabla f(x) = \frac{2c_k}{nh^d} \sum_{i=1}^{n} (x - x_i) k' \left(\left\| \frac{x - x_i}{h} \right\| \right), \tag{6.3}$$

where $g(s) = -k(s)$. More details on this algorithm can be found in [3].

The mean-shift clustering works in the two steps:

a) Starting on the data points, run mean shift procedure to find the stationary points of the density function

b) Prune there points by retaining only the local maxima. The set of all locations that converge to the same mode defines the basin of attraction of that mode. The points which are in the same basin of attraction is associated with the same cluster.

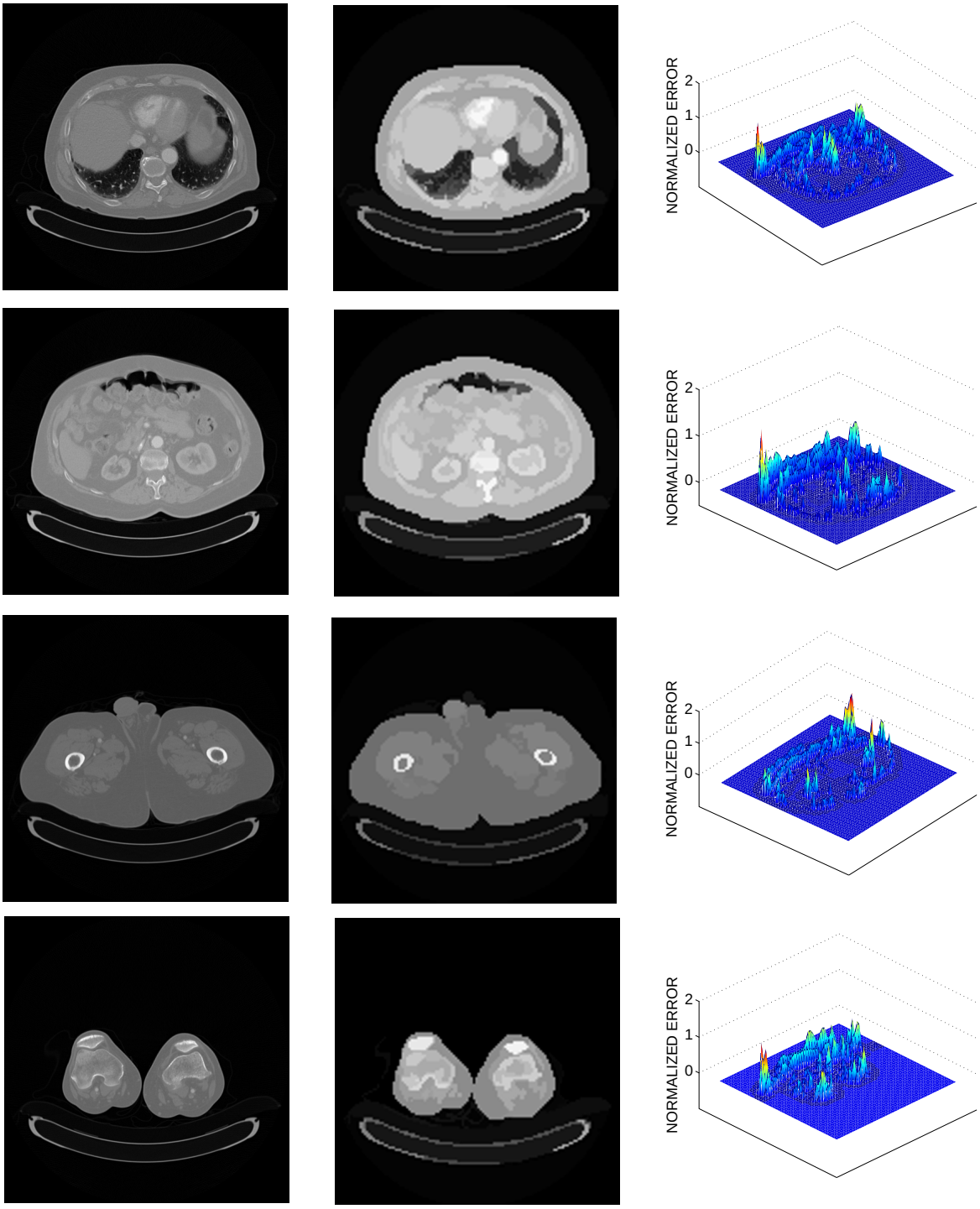

Figure 7.1: Some segmentation examples using mean-shift clustering. Left: original. Middle: mean-shift clustering. Right: normalized error.

6 Image Segmentation and Validation Process

Mean-shift algorithm was used for obtaining the boundaries between the segments. We lower the quality of the images to the resolution of 128x128 pixels from the reason of its computionally-demanding real-time application. The obtained segments with insignificant sizes were discarded. The retained segments were used as masks. Subsequently, we performed the convolution of each mask with the origin image, and compute the mean intensity value for each segment (figure 5.1 shows examples of mean-shift result with normalized error used on some selected MRI slices).

The same application was performed using the medical expert evaluation. The difference between image evaluated by the medical expert and segmented image using mean-shift was used as comparison for algorithm accuracy. Figure 7.2 shows example of medical expert evaluation.

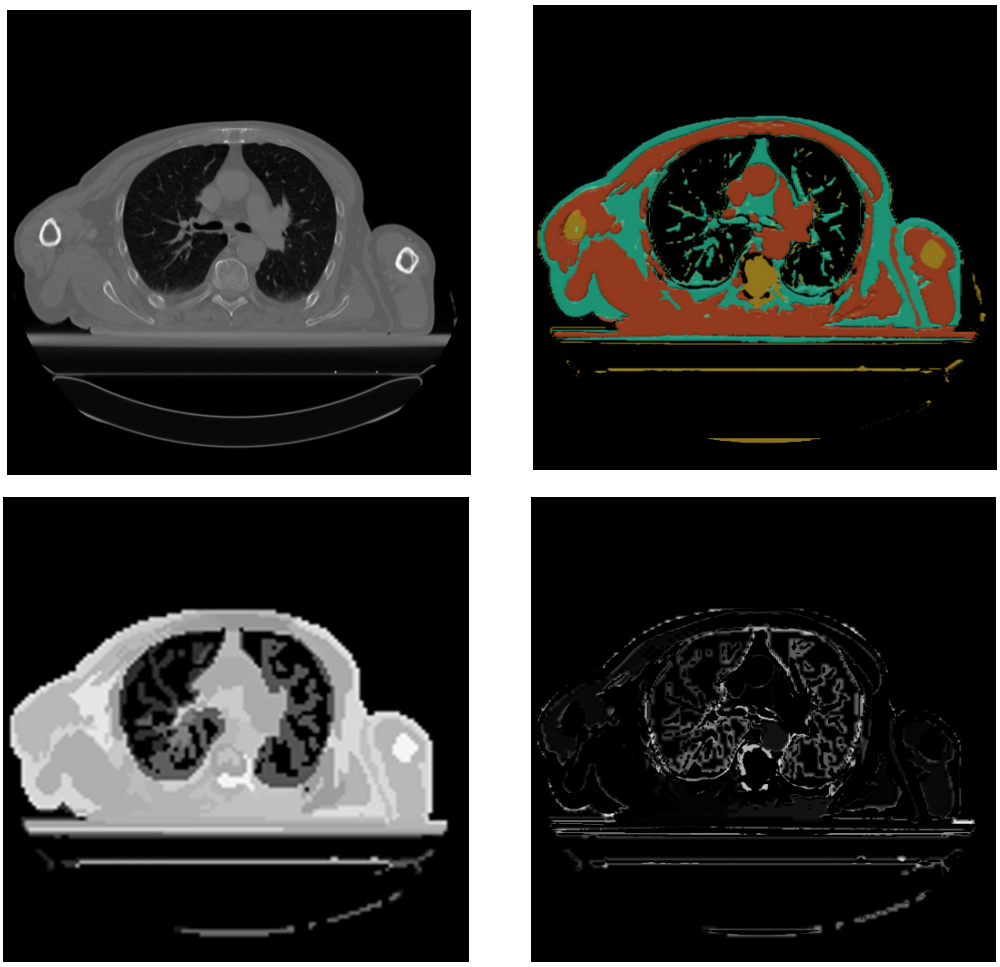

Figure 7.2: Example of comparison between medical expert and mean-shift segmentation. Upper left: original. Upper right: medical expert segmentation. Lower left. mean-shift segmentation. Lower right. difference between segmentations.

7 Results

As can be seen in figure 8.1, the accuracy of mean-shift clustering is approximately from four to eleven percent. The accuracy can be increased by the higher resolution that we could not use from the reason of algorithm computationally-demanding application. The mean-shift technique can allow us to separate tissues more precisely. Then, we can also use the different tissues including the tissues affected one by a tumor. Using the automatical body segmentation offers a great opportunity when planning many of oncological treatments.

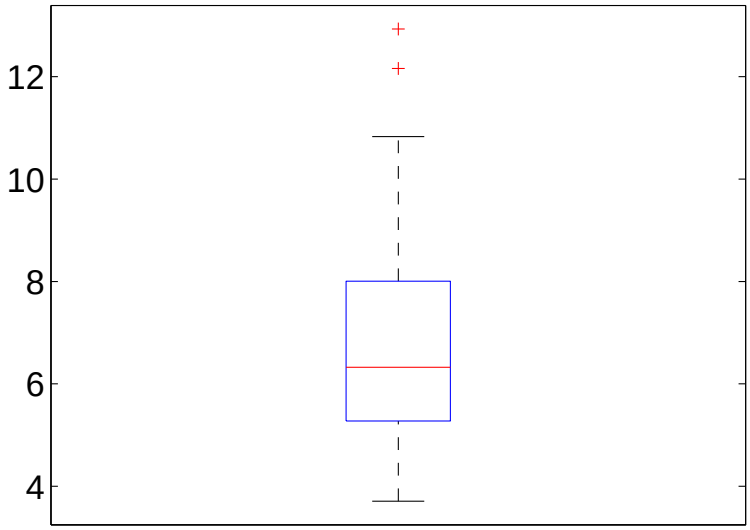

Figure 8.1: The box-plot of the mean-shift clustering algorithm accuracy in percentage

8 Conclusion

Nowadays, we are often facing the problem with the lack of quality management during the medical treatment. This paper shows the possibility of quality assurance in the segmentation process which can be helpful in the radiotherapy or hyperthermia treatment planning. Thus, it can be done with the higher level of precision.

When we obtain more accurate model of the inner body organs, tumors, and surrounding tissues from the MRI/CT DICOM data images segmentation, our treatment will be much successful and the possible side effects will be minimalized.

The results we performed show the difference between the data segmented manually by a medical expert and the automatic segmentation using mean-shift clustering algorithm.

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